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RENEWABLE ENERGIES IN THE CURRENT AND FUTURE ENERGY CONTEXT

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Energy /'ɛnədʒi/

Power derived from the utilization of physical or chemical resources, especially to provide light and heat or to work machines.

ABSTRACT

This project has two main objectives; the first objective is to determine the current situation of renewables compared to other non-renewables sources. The analysis will be done for Spain and then be compared to other countries worldwide.

The second goal is to analyze the future trend of different renewable sources and compare these trends to the existing targets in the context of sustainable development at a national level.

For the first part of the project, historical data of consumed primary energy from distinct sources will be analyzed to determine the role of renewables in the last 3 decades in comparison to fossil fuel consumption or other non-renewable sources.

The second part of the project is a deep dive to renewable sources. It will be centered on the analysis of consumed electricity produced by renewables (data from *Red Eléctrica Española*). In this section, forecast for future (2030) consumption of renewables will be made using mathematical – statistical models. The forecasting models will be Holt Winter (Exponential smoothing) and ARIMA method (AutoRegressive Integrated Moving Average). The models will then be tested and validated. Finally, the predictions will be compared to the targets for 2030 established by ***Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030***.

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1. INTRODUCTION

1.1. Background

Energy is the foundation for economic development and social progress. It is also an important factor affecting the residential environment of mankind. Energy plays a decisive role in many aspects of development of society; such as industrialization, agricultural modernization and urbanization... Energy production and usage are a major portion of any economy. Thus, it is very important to analyze the energy profile and predict energy consumption structure of the future.

Electricity generation from renewable energy sources (RES) is increasing in Europe. Much of this increase in renewable consumption is driven by ambitious targets for emission reductions set by the European Commission. In the **2050 Low Carbon Economy roadmap**, the EU set a goal of reducing emissions to 80% below the 1990 level [1.1.]. The EU also states that all sectors have to contribute to this reduction, but the sector with the highest potential for cutting emissions is the power sector. Through increasing the share of zero-emitting RES in the electricity mix. The power sector can almost totally eliminate its emissions by 2050.

1.2. Goals

This project focuses on two main goals; the first goal is to determine the current situation of renewable energy taking into account their role since the last three decades (from 1990) compared to non-renewable sources. This will be covered in the analysis of primary energy consumption, in which the evolution of renewable sources will be compared to fossil fuels and the current situation of renewables will be determined.

The second objective is to determine the future trends of renewables and how these compare to targets established by the **Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030** at a National level.

1.3. Scope of the work

As the analysis of current energy consumption and the prediction of future renewable energy consumption can be very tricky due to the number of variables involved such as political, social, economic, etc.

This work will just take into account evidences based on data and all the conclusions will be made just considering the analysis made from data observation.

The same case applies to the predictions of future electricity generated by renewables. The predictions made by the statistical models will just take into account the trend based on the past behavior inherent to the data. The generation of electricity from renewables is subjected to a lot of social, political and economic conditions that can change drastically the amount of electricity produced. As all these variables are unpredictable, they will not be considered in the scope of the project.

2. ENERGY AND DEVELOPMENT

This thesis is based on the analysis of the evolution and use of energy and renewable energy sources. Therefore, a brief explanation is needed to contextualize what is energy in general, what does renewable energy refers to, and why it is important to know the evolution of its use.

2.1. Energy

Energy, by definition [2.1.], is the ability of bodies to perform work and produce change; whether in themselves or in other bodies. There are several types of energy, such as mechanical, electrical, thermal, electromagnetic, chemical and nuclear energy. Each type of energy is named after its origin or function.

Energy as such has 4 basic properties: transformation, conservation, transfer and degradation. [2.2.]

- Transformation: “*energy cannot be created or destroyed but transformed*”. This is a direct implication of the first law of thermodynamics.
- Conservation means that at the end of any transformation process, the total amount energy is maintained, as quoted above, “*it is neither created nor destroyed.*”
- Transfer causes energy to pass from one body to another in the form of heat, work or waves.
- Degradation is a property that explains that when work is produced, part of the energy is released in the form of heat or noise (unwanted phenomena).

2.2. Usefulness of energy in today's society

Energy is a necessary asset for society progress. The socio-economic development of different countries in the world is directly related to energy. Socio-economic development of a country is directly related to the growth of GDP and the quality of life; these two largely depend on the energy use of the country.

In fact, the average energy consumption per capita is considered a very reliable indicator of the degree of socio-economic development of a society.

The plot from figure 2.1. shows the relation between GDP divided by the price (\$) of one kg of oil equivalent. As seen in the plot, there is a linear correlation between GDP and the energy consumption over years worldwide.

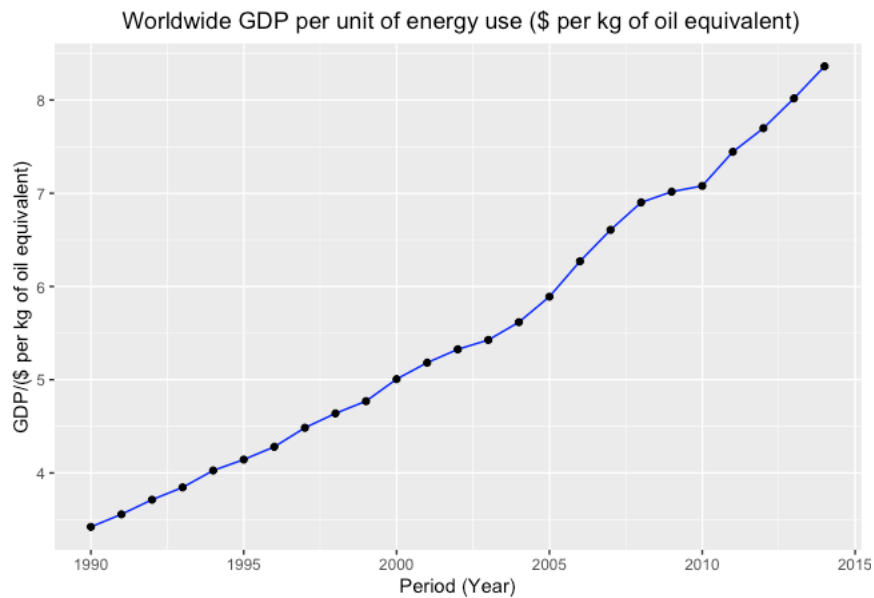


Figure 2.1. GDP per unit of energy use. Data Source: The world Bank [2.3.]

It should be said that there are very important non-numerical factors to consider in these statements. The world is suffering from a sharp rise in CO₂ emissions as there are countries in strong industrial development such as China, Brazil or India. These countries are receiving strong GDP growth per capita but at the same time they are mostly using fossil energy sources to boost this progress.

It seems that socioeconomical progress is highly correlated with greater energy consumption. But ... At what price?

There is an increasing need for a change in the global trend and in the use of fossil fuels for two main reasons: CO₂ emissions and the fact that these energies come from fuels with finite reserves. This is where renewable energy comes into play.

2.3. Depletion of Fossil fuels in Modern Civilization

It is well known that the extinction of fossil fuels will happen sooner rather than later. It took nature about 5 million years to generate the amount of fossil fuels consumed nowadays in only one year. Hence, taking into account this rate of consumption, fossil fuels are unsustainability of a socio-economic system based in fossil fuels consumption. At the current rate of consumption, the approximate lifetime of the world's petroleum, natural gas, and coal reserves is around 50 years, 70 years, and 120 years, respectively. [2.4.]

Regarding this problem, there is no doubt that a solution should be found as soon as possible. This challenge faced seems to exceed the ability to find innovative solutions as the resources and technology are not quite ready.

Taking for instance liquid fuels for transportation; motor vehicles, aircraft, trains, and ships are all based on liquid fossil fuels and have no ready alternative to liquid fuels. Moreover, rapid changeover in transportation equipment is inherently impossible as time is needed for the implementation.

According to the Global Energy Statistical Yearbook [2.5.] of 2019, Energy consumption worldwide has been increasing since 1990's. During the last decades energy has played a very important role in economic growth. In an industrialized world, economic activities are almost directly linked to the amount of energy consumed. Asia has had a very significant leap in energy consumption. This makes sense as Asia have a lot of developing countries. For example, China has been known as "The World's Factory" during the last decades.

Furthermore, other countries in continents in development such as Africa or Middle East have also been consuming more energy year over year due to their evolution and growth.

On the other hand, energy consumption in America has been fluctuating year over year with slight increases and decrease. This is again due to the shifting of industrial activities from America and developed countries to Asian countries such as China or India. The final energy consumption is computed as Chinese or Indian energy consumption even though the final product is probably shipped abroad.

Looking at the breakdown of energy consumption by country; China, The United States, India, Russia and Japan are the top 5 energy consuming countries (data from 2018)

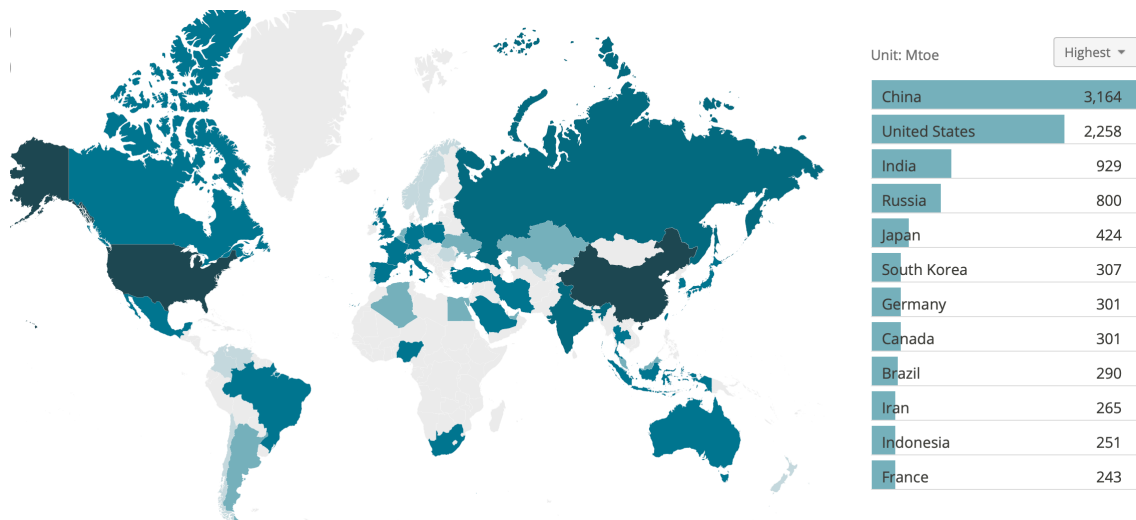


Figure 2.2. Top energy consuming Countries. Source: Global Statistical energy Yearbook [2.6.]

2.3.1. Greenhouse Effect

Earth is surrounded by gases that are retained by gravity force. All living creatures on Earth have evolved under this condition. This layer of gases has been experiencing changes in recent years. As well known, this layer is composed mainly of nitrogen, oxygen and argon. The rest of the gases are considered trace gases, found in much less concentration. These include so-called greenhouse gases.

The solar radiation that reaches the Earth's atmosphere is divided into three parts: the absorbed, the reflected and the one that reaches the Earth's surface; which is the largest part. The latter causes the surface to heat up and most of this thermal energy is re-emitted in the form of infrared thermal radiation. Part of this radiation returns to outer space, but a significant part heats up the atmosphere that absorbs it, which re-emits thermal radiation to the earth's surface, directly contributing to its warming. This balance or radiative balance between the incoming emissions, the reflected ones absorbed, added to the emitted, absorbed and re-emitted terrestrial emissions, is what causes the planet to have a temperature superior to which it would have if it did not have atmosphere.

This effect is therefore favorable for regulating Earth's surface temperature. However, the problem is anthropogenic greenhouse effect, which is the increase of this effect to dangerous levels due to the change in the concentration of greenhouse gases in the atmosphere. This fact is causing a rise in temperature, known as global warming.

So, the increase in these gases (such as CO₂) causes the balance of energy transfer to vary.

Global warming is causing harm to the Earth such as:

- Rising sea levels
- More storms and drought
- Extinction of species
- Disappearance of glaciers
- Destruction of ecosystems

2.3.2. Treaties and Directives

Throughout history, there have been several treaties aimed to reducing the rate at which climate change is affecting the world. Since the middle of the twentieth century, following the period of world wars, international problems have been tried to be dealt with through international politics. For example, the United Nations (UN) was created in 1945 as an organization of states without any cession of sovereignty to the organization.

Internationally approved treaties and conventions only enter into force if they are subsequently ratified by a large majority of a number of States and, if they so wish, any State may, even having "signed" the treaty, remain on the sidelines.

These treaties and conventions are of great importance in distributing the evolution of energy use worldwide. At the European level, an Intended Nationally Determined Contribution (INDC) was signed, agreeing to a 40% reduction in greenhouse gas emissions for domestic use of energy by 2030, compared to 1990. [2.7.]. Part is this solution is the use of renewable energy sources.

2.4. Renewable Energy

Renewable energies are those energies from natural sources. These sources are virtually inexhaustible (as they come from sources such as sunlight, wind or the movement of sea waves, among others) and have zero CO₂ emissions in their operation. They are considered environmentally friendly primary energies as they do not produce by-products from their operation.

The main renewable energies sources and the some of the ones that will be analyzed in this project are:

- Hydraulic energy, which is the energy that is transformed from the potential energy difference in waterfalls. They usually take advantage of the rivers to drive the relevant turbines that drive the electric generator.
- Solar thermal energy, which is the energy collected from the incident solar rays on solar panels. This energy is transformed directly into heat, which makes it a little different from the rest: it is mostly used to obtain hot water for domestic or industrial consumption or to heat buildings.
- Solar photovoltaic energy like solar thermal energy, it also consists of collecting incident solar rays using solar panels. In this case the light obtained from solar rays are transformed into electrical energy using photovoltaic cells. There are different photovoltaic technologies used in different countries in the world to optimize the use of energy from this source.
- Biomass energy, which is the energy obtained from the use of organic materials that contain a large amount of energy stored in the form of carbon that can be transformed into thermal energy, electricity or fuels of plant origin such as biogas or biofuel.
- Wind energy is the energy obtained from the force of the wind, using kinetic energy to transform it into electrical energy via wind turbines.
- Geothermal energy is obtained from the use of the Earth's internal heat, which reaches to some extent to the Earth's surface.
- Tidal energy is the energy obtained from the movement of sea tides.

2.5. Conditioning factors of renewables usage

This section will try to summarize the set of most important factors in the evolution of the use of renewable energies. These aspects will be divided into technology and economics, legislation and social factors, such as awareness.

2.5.1. Technology and economics. Renewable resources

First, the economic viability of using renewable energy should be attractive investors and small consumers. Therefore, technological advancement is vital when it comes to taking advantage of the renewable energy sources that are offered to increase the performance of the facilities, reduce maintenance costs or increase the use of space.

Thus, the economy tends to have a very important weight for consumers when choosing the energy source. The economic profitability of an installation is marked not only by technology, but by the legislation in force in each country, either in the form of special remuneration, premium treatment or discounts when it comes to use this type of energy. These two aspects, however, depend on the renewable resources that each place has available. Spain is a country with very present sources of renewable energy, with a large usable territory, great solar incidence, good sources of wind and other valuable resources.

2.5.2. Legislation

As well known, the legislation on every country will vary largely depending on its politics. The scope of this section is Spanish legislation.

The legislation has a very important effect when it comes to the use of renewable energy; not only the costs of installation, but also those of operation and maintenance of each energy source depend on the laws. All in all, the economy, legislation and awareness make up the most important triangle of aspects: legislation will depend on a country's awareness of climate change and its economy and renewable resources.

In recent years, Spanish legislation has undergone several changes, mainly due to a very large tariff deficit in the electricity sector, which makes it impossible to continue with the premiums and special schemes proposed by the *PSOE* government in 2008.

Below is a summary of the most important changes in Spanish regulations.

The movement to improve the balance of use of renewable energy in the Spanish electricity system began in 2005 with the Renewable Energy Plan *Plan de Energías Renovables (PER)* [2.8.] and an action plan to improve the energy efficiency. These new contributions meant that the installation of renewable power and the subsequent use of renewable energy grew at a great pace, which made it possible in 2010 to reach a total of almost 12% of renewable energy consumed compared to other energy sources at a National level.

Real Decreto Ley 661/2007 [2.9.] regulated the activity of electricity production in a special regime, replacing the previous ***Real Decreto Ley 436/2004*** [2.10.] respecting its basic scheme. It contained generous incentives for the use of renewable energy, with the option of double pay (regulated or market rate). The government ensured the payment of premiums, figures of up to 20 or 25 years of investment. Several cases directly affected this decree so generously that, within a few years of its implementation, it substantially increased the existing tariff deficit in the state. A very important fact of this Decree is that it protects the investor when the income derived from the market price was excessively low. One of the most promoted technologies was photovoltaic solar thanks to the favorable economic regime for investors, which led to a spectacular rate of such installations. This uncontrolled growth was the main reason for the publication of ***Real Decreto Ley 1578/2008*** [2.11.], which created a new remuneration scheme for solar photovoltaic technology by reducing the price set for the sale of electricity to the system, specifically classifying the different types of photovoltaic solar to regulate its use more strictly.

Directive 2009/28 / EC [2.12] caused minor changes to the previous regulations, with ***Real Decreto Ley 1614/2010*** [2.13] and ***Real Decreto Ley 14/2010*** [2.14], which limited remuneration to equivalent hours of operation with the right to a premium in wind, thermoelectric and photovoltaic installations depending on the climate zone and the technology used, to improve energy efficiency.

A very important law is ***Real Decreto Ley 1699/2011*** [2.15.], also called the law of **self-consumption**, which promoted the implementation of small and medium power facilities on urban land with the aim of promoting a new regulatory framework that favors the planned facilities in the medium term.

With the change of government at the end of 2011, there were changes in legislation that directly affected the premiums and subsidies given to renewable energy, among others. In 2012 there was a change of government that accelerated the process of changing legislation.

From the year 2000 onwards, there was a dynamic rise in fossil fuel prices, which was already beginning to generate a growing tariff deficit. This deficit grew exponentially when a serious error was made in the forecast of installed power in Spain: the photovoltaic power became 10 times higher than expected, which meant the remuneration and premiums which the government had to pay would grow in the same proportion.

Thus, the new government changed the regulations to stop the exponential and progressive rise in the tariff deficit with a reform of the electricity system that, in short, reduced the remuneration for the production of electricity from renewable sources in more than 30% of the total.

All this induced ***Real Decreto Ley 1/2012*** [2.16.] to be approved on 27 January 2012, which abolished incentives for the construction of new facilities to reduce the high costs of premiums according to the Government. The argument was that the installed power targets for wind, solar thermoelectric and solar photovoltaic energy had been exceeded, which meant an "imbalance between production costs and the value of premiums."

The main actors of the Spanish Electricity Sector reform were the ***Real Decreto Ley 9/2013*** [2.17.] and the ***Real Decreto Ley 413/2014*** [2.18.], which substantially changed the distribution of remuneration to the investments of the energy sector.

Real Decreto Ley 9/2013 arbitrarily repeals all laws of equal or lower rank that have been in force until then (such as ***Real Decreto Ley 1578/2008***, which established remuneration for the production activities of electricity from photovoltaic solar technology). All renewable energy tariffs are eliminated.

Thus, much of the remuneration of the facilities were given by a term conditioned and calculated by the State (reasonable profitability) which will mean a decrease in remuneration up to half of those received by the previous Royal Decrees (***Real Decretos***).

The production of electricity from renewable sources is also affected by ***Real Decreto Ley 24/2013*** [2.19.] to regulate the electricity market in Spain, which had incorporated several changes in market regulation. The effect of this on renewables was to transfer them all to the new specific remuneration, which took into account variables other than special regime.

In June 2014, ***Real Decreto Ley 413/2014*** was published, a document that aims to regulate the activity of electricity production from renewable energy sources, cogeneration and waste. The most important change was that it repeals all previous remuneration laws, causing great economic losses to many users and investors due to the arbitrary change in regulations.

Therefore, from the period 2013-2014 there was a great change in the dynamics of the evolution of the use of renewable energies in Spain.

2.5.3. Climate change. Directives and awareness

Finally, another of the most important conditioning factors in the use of renewable energy is the awareness that fossil fuels are being depleted, climate change is becoming increasingly evident and its damage more irreversible than ever. People must realize that nowadays technology allows not having energy dependence on a few energy resources. Every country must be aware that its energy independence is given not only by its capital, but also by its renewable energy sources.

2.5.4. Importance of renewable energies for progress

As stated above, energy is essential for progress. However, progress is beginning to receive some limitations due to the increase in the concentration of CO₂ in the atmosphere. The constant and ever-increasing concentration is directly affecting the Earth's climatic conditions (Greenhouse Effect as discussed before).

Renewable energies play an important role in this fight, as due to their zero CO₂ emissions in operation they would directly help to reduce emissions and concentration of greenhouse gases in the atmosphere. Therefore, it can be stated that renewable energies are of crucial importance in the development of countries as they would allow them to progress socio-economically without aggravating the Greenhouse Effect.

The chart below is the evolution of CO₂ emissions per capita since 1990. It can be seen in this chart (see figure 2.3.) that the general trend is an increase in CO₂ per capita from 1990. Although there has been a decrease since 2013, this decrease has been extremely small given that energy consumption in the last 40 years has increased dramatically.

It should be noted that renewable energy is not a permanent solution, as its purpose is not to reduce the concentration of CO₂ in the atmosphere but to maintain it. Therefore, they are considered an element of utmost importance to slow down the process and to be able to find formulas to reverse the changes in the atmosphere.

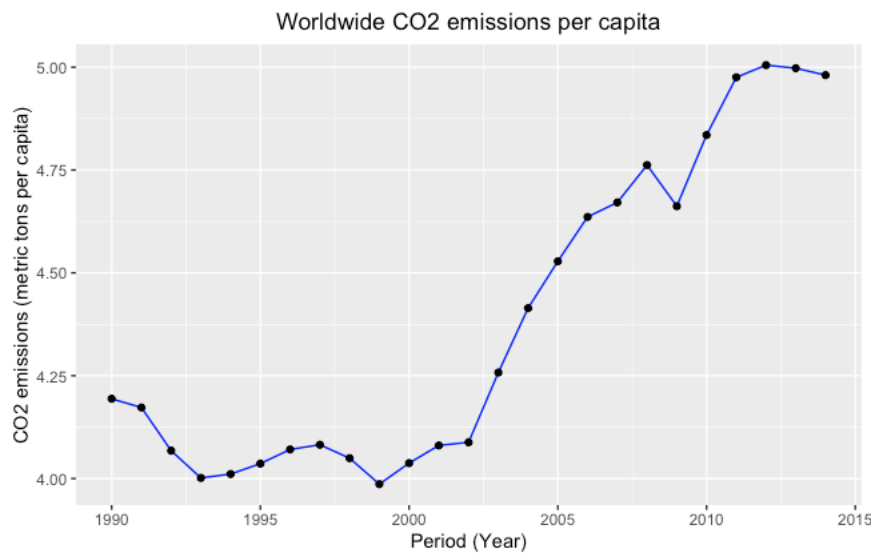


Figure 2.3. Worldwide CO₂ emissions per capita. Data Source: World Bank [2.20]

3. PRIMARY ENERGY CONSUMPTION

Primary energy is the one that is directly obtained from nature. It has not been subjected to any human engineered conversion process. It is energy contained in raw fuels, and other forms of energy. Primary energy can be non-renewable or renewable such as Coal, oil, natural gas, hydro, wind, biomass, solar, uranium...

As discussed in the previous section, non-renewable energies are a large part of energy consumption worldwide. The following is an introduction to primary energy consumption.

3.1. Primary energy consumption per capita

In this section, primary energy consumption in Spain will be analyzed and then compared to the rest of the world.

In order to make a fair comparison, energy consumption is normalized for each country/continent analyzed. This is done by dividing the total amount of primary energy consumption by the total number of inhabitants; the result is primary energy consumption per capita.

The following chart (see figure 3.1.) shows the primary energy consumption per capita of different continents compared to Spain. The data is in Mtoe/Million people (where Mtoe stands for Million tons of oil equivalent).

As observed in the chart, Spanish primary energy consumption per capita is greater than world average primary energy consumption per capita. It is interesting to notice that from 1990 to 2008, Spanish primary energy consumption highly increased, while the trend for the rest of European countries was a decrease. From 2008 however, the consumption decreased due to the economic crisis as energy consumption is highly correlated to a country's economy as discussed in the previous section. And Spain took a major economy hit during the crisis.

Again, it is noticeable the increase in primary energy consumption for developing countries in continents such as Asia and Africa in the last 3 decades.

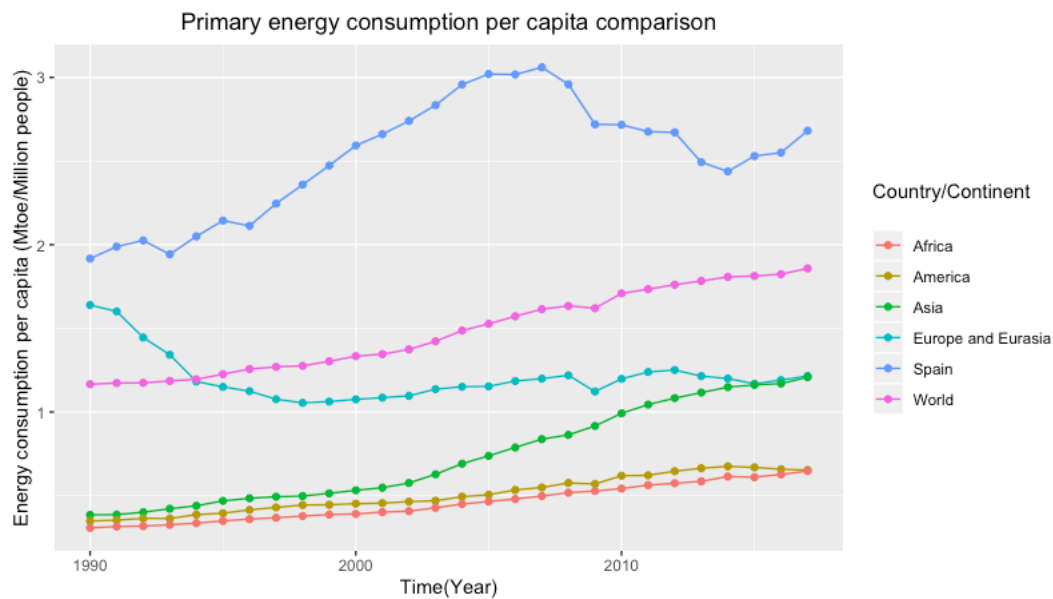


Figure 3.1. Primary energy consumption per capita. Data source: IEA [3.1.]

The next section is an in-depth analysis of the primary energy consumption in Spain compared to the world. In this case the primary energy consumption is spread in absolute numbers. The main objective in this section is to see the trend and evolution by different energy sources.

3.1.1. Primary energy consumption Worldwide

Energy consumption has been increasing in the last years. For the last decades, the increase in energy consumption has been attributed to the increase of industrial activity and the growth of economy.

The chart below (see figure 3.2.) shows the evolution of primary energy consumption since 1990 Worldwide. According to the data, there has been a year to year increase in the consumption of primary energy. As it can also be observed, the increase is present in all the different sources of energies.

Renewable energy has been growing but as opposed to the initial intention, the increase in renewable energy is relatively small compared to the rest of energy sources. Hence it can be observed that there has not been a substitution of fossil fuels by renewable sources, rather all energy sources have increased.

The main concern of the future is the extinction of fossil fuels and the contamination of their products. Research in the field of renewable energies are being carried out in order to replace fossil fuels with renewable sources. But as shown in the chart in figure 3.2.,

fossil fuels are being used more than ever, while renewable sources still need a greater leap forward.

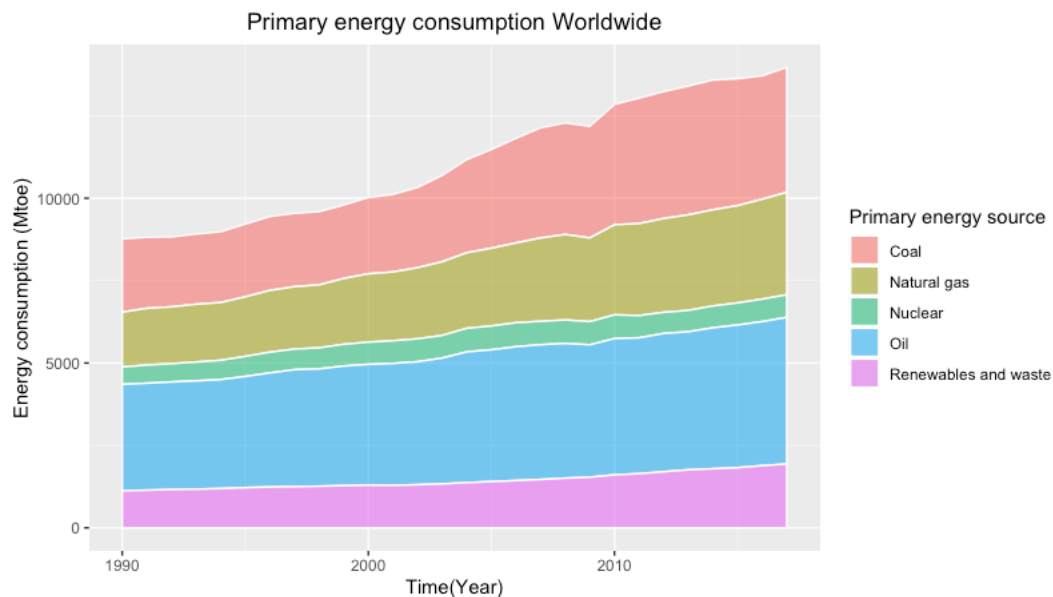


Figure 3.2. Primary energy consumption Worldwide. Data source: IEA [3.1.]

3.1.2. Primary energy consumption Europe

As oppose to the situation Worldwide, primary energy consumption has been fluctuating in European countries. There has been a noticeable decrease in oil consumption from early 1990s to early 2000s

Since early 2000s, all energy sources have been increasing year over year regardless of the fluctuation. The reason seems to be the same as what has been happening globally in the last decades. Economic growth has been increasing and with the increase in industrial activity and growth energy demand has been one of the key factors in this growth.

Regarding renewable energy sources, the increase has been very small almost imperceptible. This shows that fossil fuels are still being used in large quantities compared to renewables (see figure 3.3.)

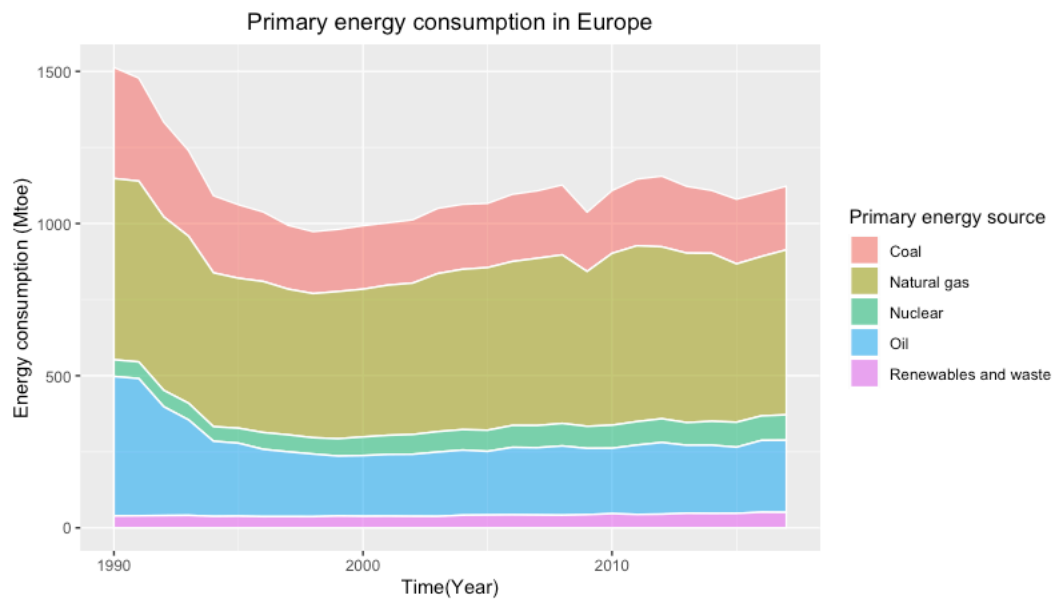


Figure 3.3. Primary energy consumption in Europe. Data source: IEA [3.1.]

Some of the most primary energy consumption countries in Europe are the flowing; Germany, France and United Kingdom being the top three countries with mayor primary energy consumption (see figure 3.4.).

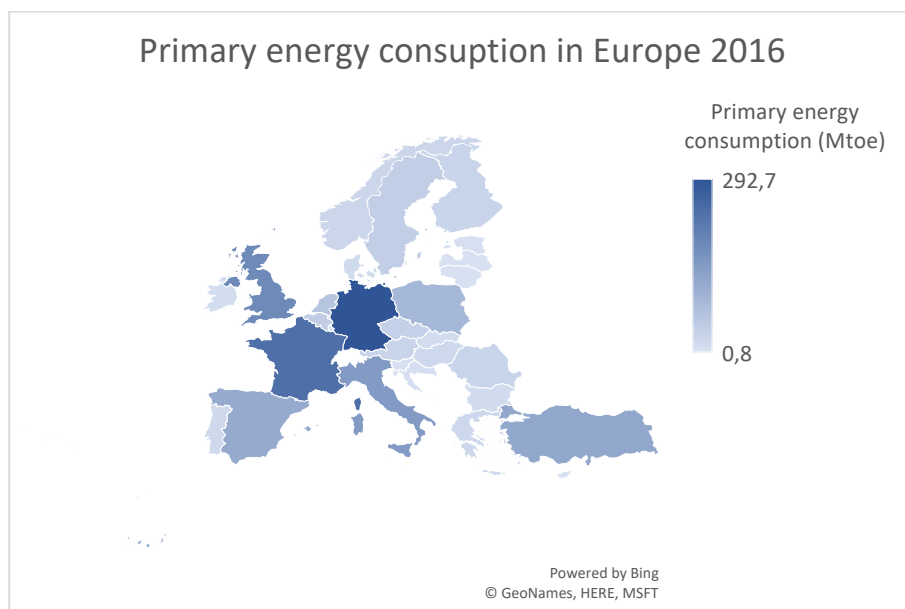


Figure 3.4. Top primary energy consumption in Europe. Data source: IEA [3.1.]

3.1.3. Primary energy consumption Spain

Similarly like the situation worldwide and in Europe, primary energy consumption has been increasing during the last decades in Spain. From the chart in figure 3.5, it is noticeable the decrease in energy consumption from 2008 to 2014 and then it starts to recover again. This is due to the economic crisis in 2008 which reduced industrial activity in large portion in Spain.

Regarding the chart (see figure 3.5), it is noticeable that Oil and Natural Gas are two of Spanish's main primary energy source. It is also interesting to notice how Nuclear energy source is relatively much larger in Spain compared to the rest of Europe and to the rest of the world.

Renewable energies have been increasing year over year, although not in large portion. Renewable energies have not yet substitute rest of energy sources. Furthermore, the proportion of growth of other energy sources have been even greater (for example Natural gas and oil).

The percentage of adoption of renewable sources in Spain is greater than the average of the rest of European countries, but still there is room for a greater growth.

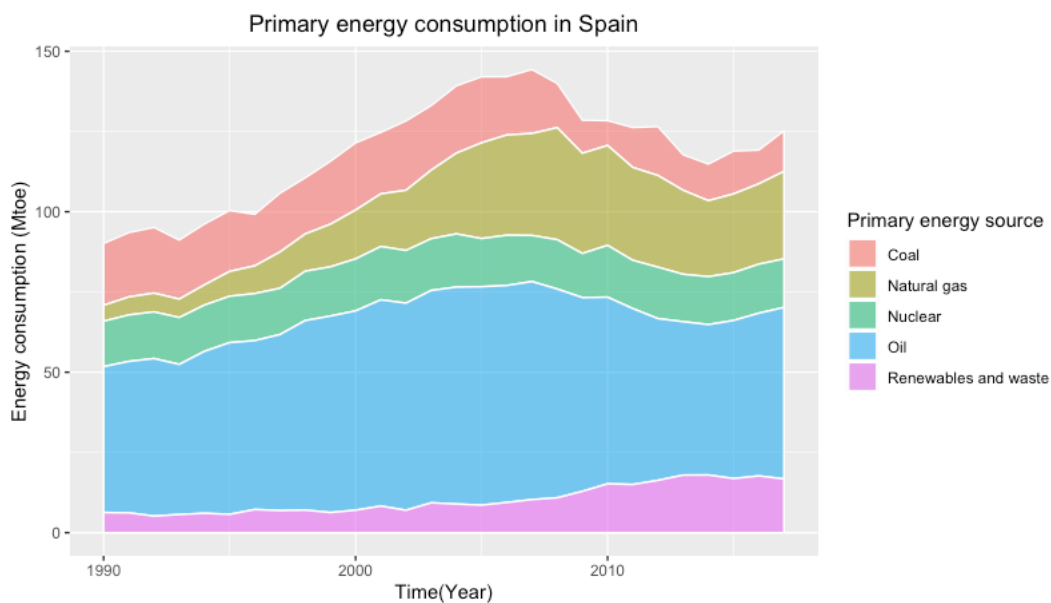


Figure 3.5. Primary energy consumption in Spain. Data source: IEA [3.1.]

3.1.4. Primary energy consumption China

Some developing countries have had a great play in energy consumption during the last 3 decades. One of these countries is China; which has become the world's factory. For this reason, China is analyzed to see how being the world's factory has impacted the country's energy consumption.

Chinese share of energy consumption is very high in Asia. The consumption of fossil fuels has increase drastically; especially Coal, Oil and Natural gas (see figure 3.6). This is the price China has to pay in return of its ever faster growing economy. This huge amount of fossil fuels consumed in a relatively short time has led to a large amount of CO₂ contributing to the Greenhouse Effect and a general pollution in China.

Until now, fossil fuels and climate change were just concern of few organizations, but due to the real treat of fossil fuels and the business opportunities that renewable sources present, companies and organizations are willing to invest in the sector. As a result, the growth of renewable energy capacity has been very relevant during the last decade.

Chinese government is very concerned about the extinction of climate change and how renewable energy industries can become some of the most profitable industries worldwide in some short years to come.

China is actually one of the world's leading countries in renewable energies, investing large amounts of money in renewables. As a result, renewable energy consumption has been increasing in the last years in China. (figure 3.6).

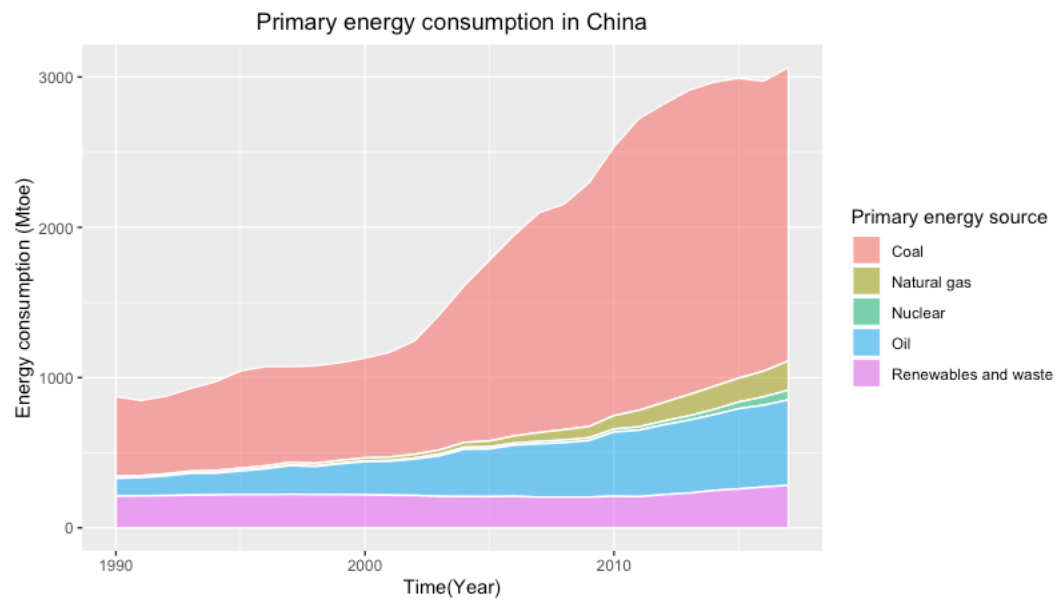


Figure 3.6. Primary energy consumption in China. Data source: IEA [3.1.]

3.1.5. Primary energy consumption USA

Jointly with China, USA has the world's largest economy. The next section is centered on the analysis of evolution of primary energy consumption in USA.

From figure 3.7, it is noticeable that USA's main sources of energy supply are Coal, Oil and Natural gas, all of them from non-renewable sources.

The adoption of USA of renewables is relatively low compared fossil fuels. It is a small increase trend which could be much bigger in the near future.

USA like China is also one of the main countries concerned lately about climate change. While noticing the business opportunities in renewables, USA has also started to invest heavily in renewables.

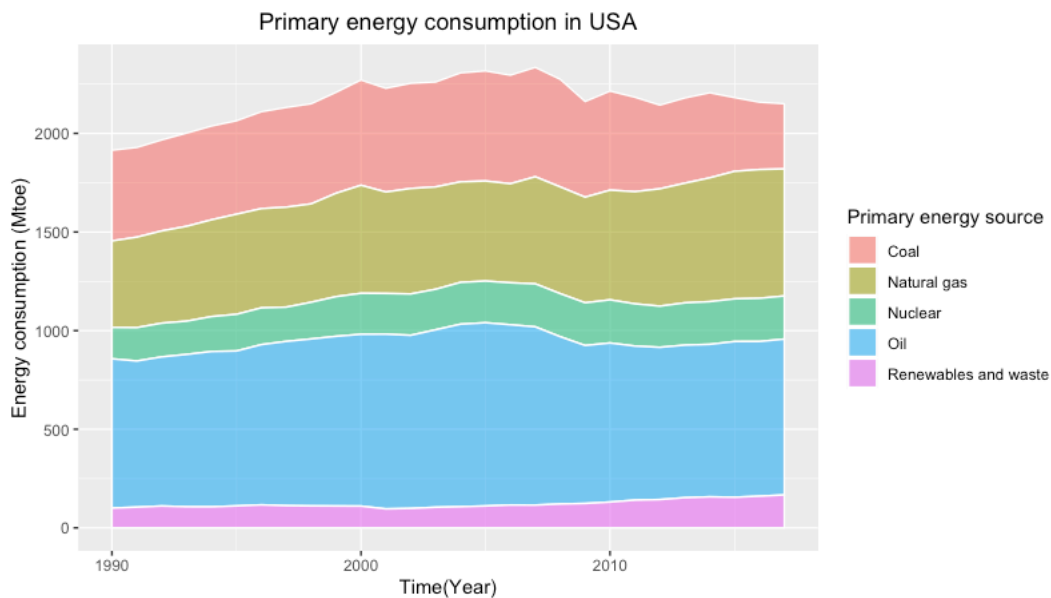


Figure 3.7. Primary energy consumption in USA. Data source: IEA [3.1.]

3.2. Adoption of Renewable energies

As seen in the data analyzed in the previous section, renewables are being used everywhere worldwide and its adoption is increasing year over year. In the following charts, some data will be analyzed to determine the percentage of renewables compared to the rest of energy sources used in 1990 vs 2017 worldwide and specifically for Spain. This analysis is to have a bigger picture on how far renewables have come in the last 3 decades.

The charts below show the primary energy consumption by sources Worldwide for 1990 and 2017 respectively. As seen from the charts from figure 3.8, the consumption of coal has remained quite the same, while the consumption of oil has reduced from 36,88% to 31,85%. By contrast, the consumption of energy from renewables and waste has increased from 12,81% to 13,86%. This further confirms the interest in renewables in the last decades and the reduction of consumption of fossil fuels.

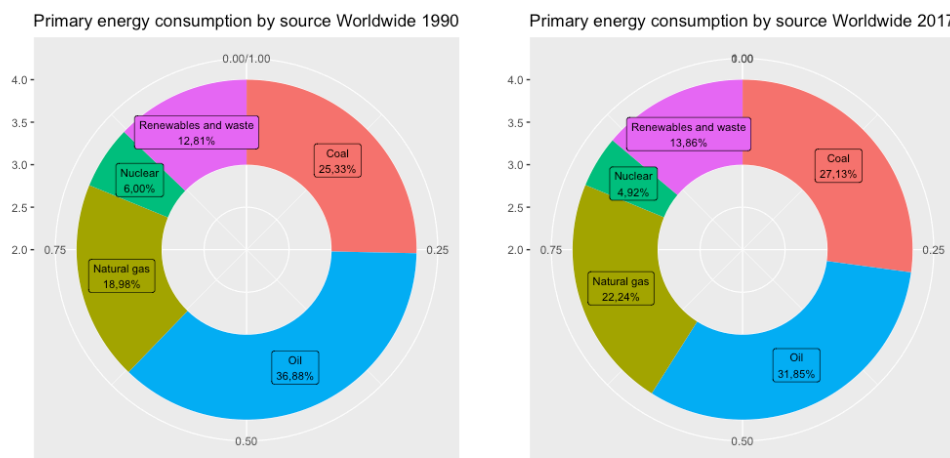


Figure 3.8. Primary energy consumption by source worldwide (1990 vs 2017). Data source: IEA [3.1.]

As anticipated, consumption of renewables has also increased in Spain. It was just around 6, 97% in 1990 increasing to 13,38% in 2017. A growth of around 6,41% in 27 years. With the exponential adoption of renewable sources, this percentage should increase by a large portion in the coming years.

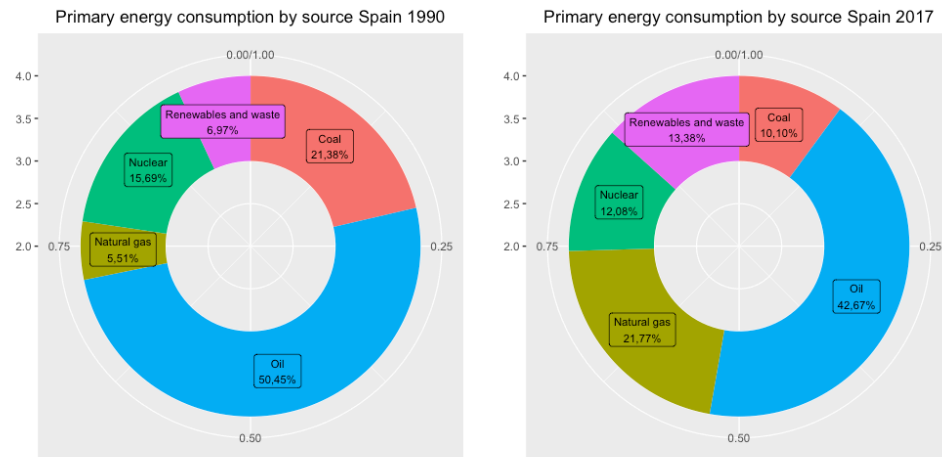


Figure 3.9. Primary energy consumption by source in Spain (1990 vs 2017). Data source: IEA [3.1.]

Finally, the next two charts (see figures 3.10. and 3.11.) show the amount of investment in renewables versus the amount of investment in fossil fuels worldwide compared to Spain. The numbers are absolute figures, so the studies here is to analyze the trend rather the amount as obviously investments worldwide will be greater than in Spain.

The following charts shows the investment worldwide in fossil fuel sources versus the investments in renewable sources. Regarding figure 3.10, around 1990's fossil fuels had a much higher investment in comparison to renewables. But as time went by, the major part of the investments shifted from fossil fuels to renewable sources. From early 2010's the investments in renewables if far superior to the investments in fossil fuels.

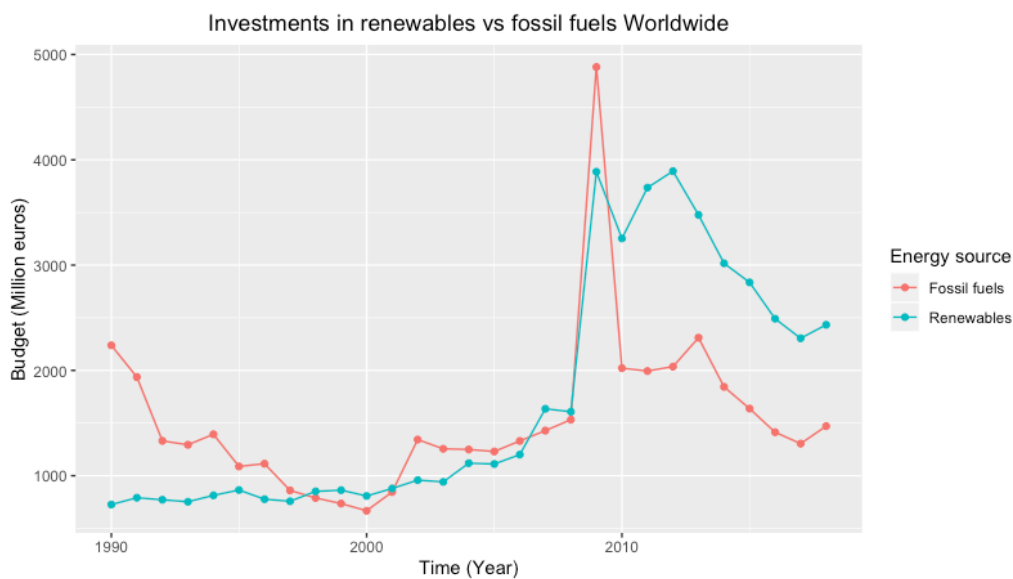


Figure 3.10. Investments in renewables vs fossil fuels worldwide. Data source: IEA [3.1.]

In order to compare the situation in Spain to the rest of the world, the same plot is made for Spain.

As seen in the chart below (see figure 3.11.), investment in renewable sources has always been superior to investments in fossil fuels since 1990. This gap became wider in 2010s. Being 2011 the year with the largest investment in renewables regarding the time frame analyzed (1990 to 2017), around 150 million euros invested.

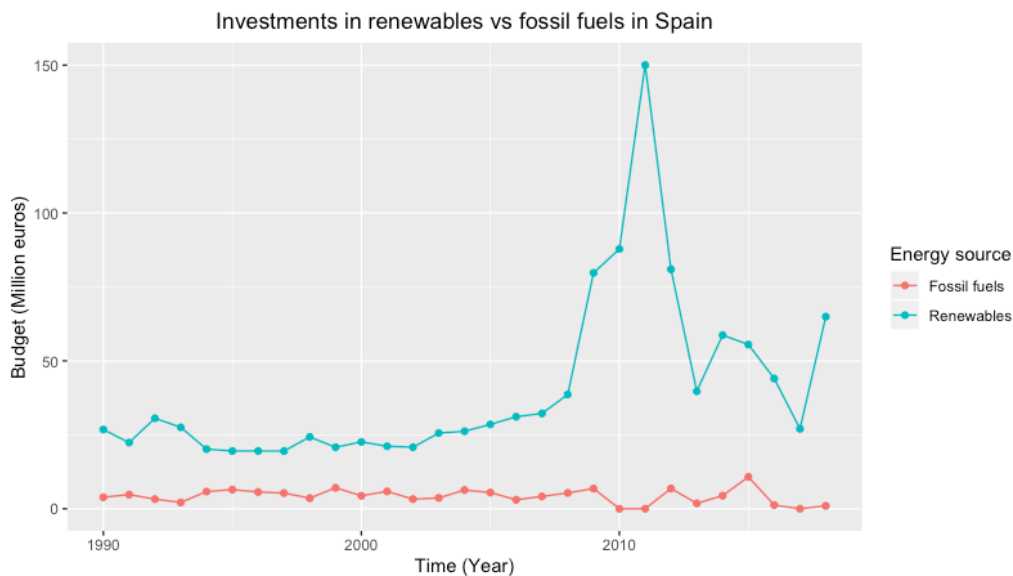


Figure 3.11. Investments in renewables vs fossil fuels in Spain. Data source: IEA [3.1.]

3.3. Consumed renewables by sources

The last section is was about the quantity of renewables consumed compared to the rest of primary energy sources.

This section is a deep dive in the different kinds of renewable sources and their evolution. Which renewables are most used currently, and which renewable sources are likely going to have the greatest adoption in the near future? These questions will be answered in the section for Spain, Europe and worldwide.

Even though renewables were analyzed as primary energy in the last section (expressed in Mtoe), in this section the analysis is based on consumed electricity from renewables. This is due to the fact that almost all renewables are consumed as electricity, hence the unit for the analysis now on will be GWh/Year.

3.3.1. Consumed renewables by source Worldwide

Starting worldwide, the accumulative bar chart in figure 3.12 shows the evolution of the consumed renewables worldwide. As it can be observed, the growth in the last 17 years has been quite significant for renewable sources. Based on the chart from figure 3.12, from 2000 the basic and major renewable energy source was Hydropower, all the other sources were almost inexistent. Since then all renewable energy sources have been growing year over year. It is important to focus attention on Wind and Solar power as these two have gain a very significant leap in growth in the last 2 decade.

The reason for the huge growth in solar and wind power is due to the cost of technology. In the early 2000's the technology for installing wind and/or solar panels was very expensive. But as it usually occurs with technology, it gets cheaper over time as investigation permit the mass production of it, leading to a cheaper product. This phenomenon and the desire of the world to have a sustainable energy source in the last years can be the main reason of why renewable sources as wind and solar power have gained such importance.

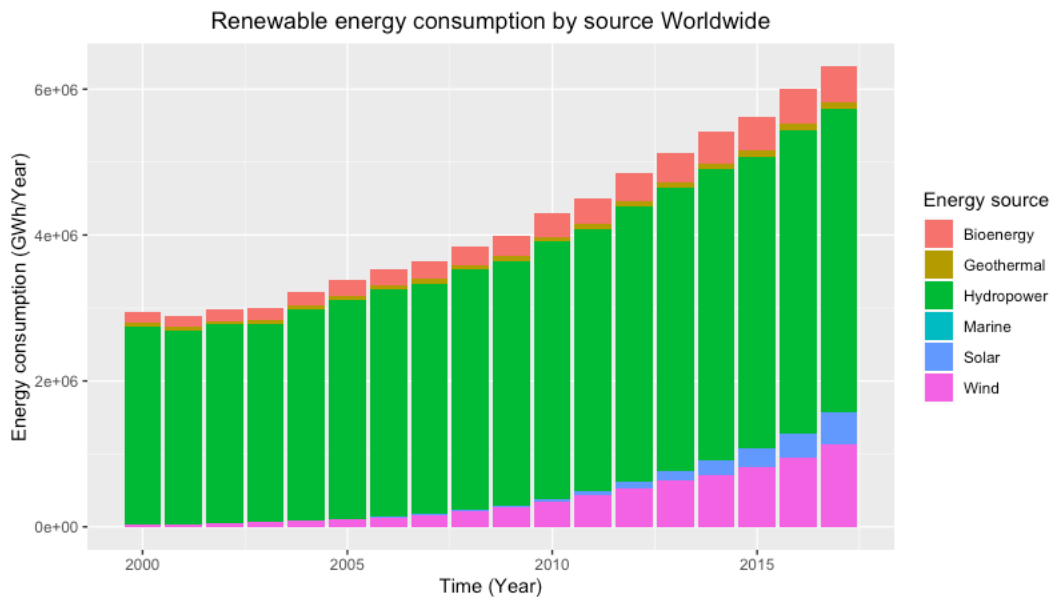


Figure 3.12. Renewable energy consumption by source worldwide. Data source: IEA [3.1.]

3.3.2. Consumed renewables by source in Europe

Regarding the situation in Europe; it follows the trend worldwide, as every country seems to follow the trend on investing in solar and wind power as the main sources of the future. These two technologies have been becoming cheaper each year and they seem to be the ultimate solution for the extinction of fossil fuels, as solar and wind are unlimited resources on earth.

Regarding the chart in figure 3.13; Hydropower has reduced share significantly giving way to wind and solar resources which have grown larger every year, especially wind energy in the case of Europe. It can be observed that solar was almost inexistent until 2010 when it started gaining traction. From there it has increased by a large amount in the last 8 years

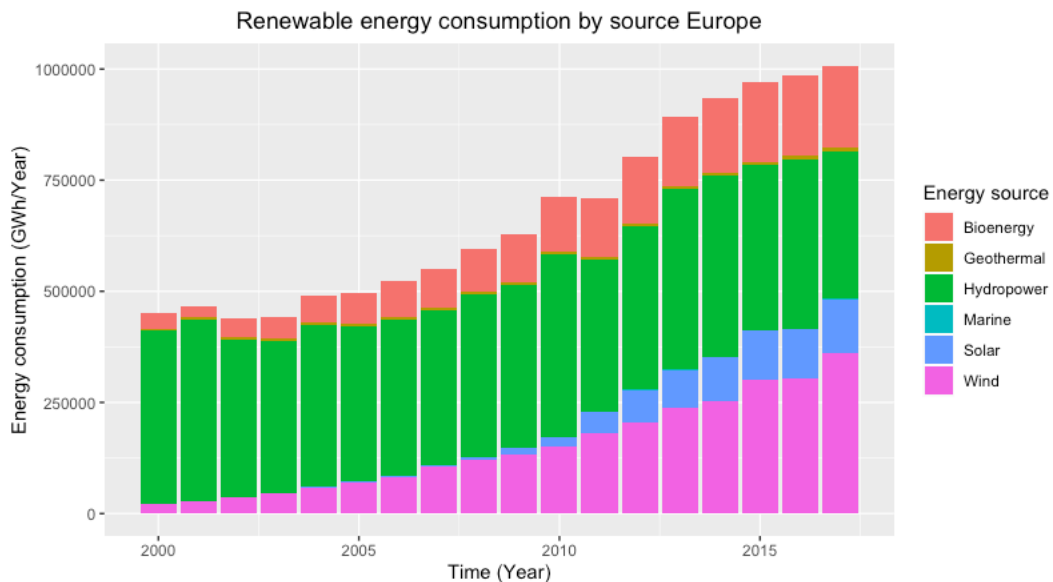


Figure 3.13. Renewable energy consumption by source in Europe. Data source: IEA [3.1.]

3.3.3. Consumed renewables by source in Spain

Spain as the majority of European countries started investing in solar energy seriously around 2006. From then, there has been a large year over year increase for solar sources. From the chart in figure 3.14, it is noticeable that the amount of solar energy consumed is quite the same from 2015 to 2017. This situation can be explained as consequence of a law imposed by Spanish government. The popularly known as “*Impuesto al sol*” which was a law approved in 2015. This law forced houses using photovoltaic panels to pay a tax for using the electric network. The main objective of this law was to avoid the loss of capital of the main energy companies in Spain. As consequence, installing photovoltaic panels wasn’t attractive to people anymore. In 2019, the law was removed. This seems promising for solar energy in Spain, as the government has decided to back on this law allowing people to use solar energy under certain conditions. As a result, there should be an increase in solar energy consumption in the near future.

On the other hand, wind power has had a very large increase in trend since 2000. It is now one of the main sources of renewables in Spain together with hydropower. Hydropower has been the main renewable source for a lot of years. Actually, electricity consumption from wind is very similar to hydropower currently. The difference was very large 17 years ago. This show how far wind and solar energy have come.

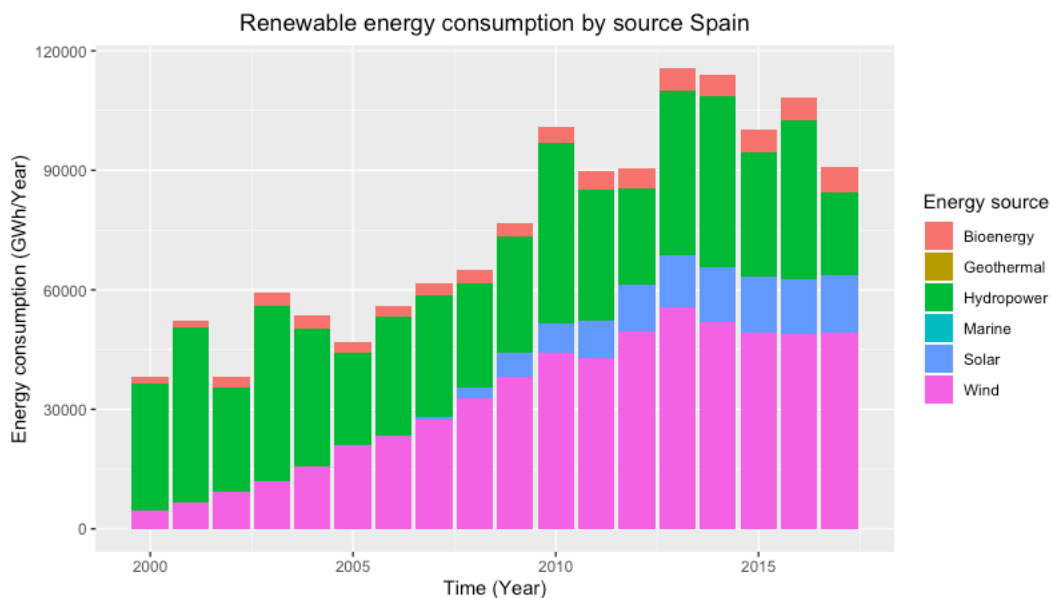


Figure 3.14. Renewable energy consumption by source in Spain. Data source: IEA [3.1.]

4. TIME SERIES ANALYSIS

Until now, the current situation of renewables compared to other energy sources has been determined. The following section (Time series analysis) is a tool needed for the upcoming sections where the future of renewables energies will be predicted using statistical models. These predictions will then be compared to targets established by *Plan Nacional Integrado de Energía y Clima*.

Understanding time series is important to understand the forecast models that will be used to predict future renewable electricity consumption. Proper time series terms will be discussed in this section in order to understand the trends and patterns that are inherent to time series data.

Time series analysis is a statistical technique that deals with time data, or trend analysis. Time series data are data in a series of particular time periods or intervals. [4.1.] For this work, the time series data is organized in months. This means every register of data stands for consumed electricity from a particular renewable source by month. There is an entire section dedicated to dataset where the data will be explained deeply.

4.1. Properties of Time Series

Time series data usually have the following feature inherent to them; Stationarity, Seasonality, Trend and Remainder.

4.1.1. Stationarity

In order to perform a proper time series analysis, the data has to be stationary; A stationary process has the property that the mean, variance and autocorrelation structure do not change over time. Stationarity can be defined in precise mathematical terms, but for the purpose of this work, stationarity is synonym to a flat looking series, without trend, constant variance over time, a constant autocorrelation structure over time and no periodic fluctuations (seasonality).

To attain proper results for the predictions, the data will have to be de-trended in order to perform the time series analysis. This will be done and plotted with a mathematical

function in R software which decompose time series data to its basic elements (season, trend and remainder) [4.2.]

4.1.2. Seasonality

Seasonality is a periodic fluctuation. For the data analyzed, it can be observed for sources such as solar photovoltaic and solar thermal where energy consumption from these sources are much higher in summer than in winter. This pattern repeats itself each year. [4.3.]

4.1.3. Trends

Trend is a consistent directional movement in a time series. Trends can be either deterministic or stochastic. The former allows the provision of an underlying rationale for the trend, while the latter is a random feature of a series that is unlikely to be explained. The data of consumed renewable electricity presents trends; these trends are generally an increase or decrease of the consumed electricity from the renewable source over time. [4.3.]

4.1.4. Remainder

Remainder or Noise is a non-systematic component that is neither Trend nor Seasonality within the data. It is usually due to a random factor that is mostly unexplainable. [4.4.]

4.2. R software and R Studio

The software used for the analysis is R. R is a free software environment for statistical computing and graphics. It compiles and runs on a wide variety of UNIX platforms, Windows and MacOS. It is an opensource program which is free for everyone to download.

Using just R software is difficult because it just works with the computer terminal and makes it difficult to program. To solve this problem, there is a companion software for R called R Studio which has a much more user-friendly interface. [4.5.]

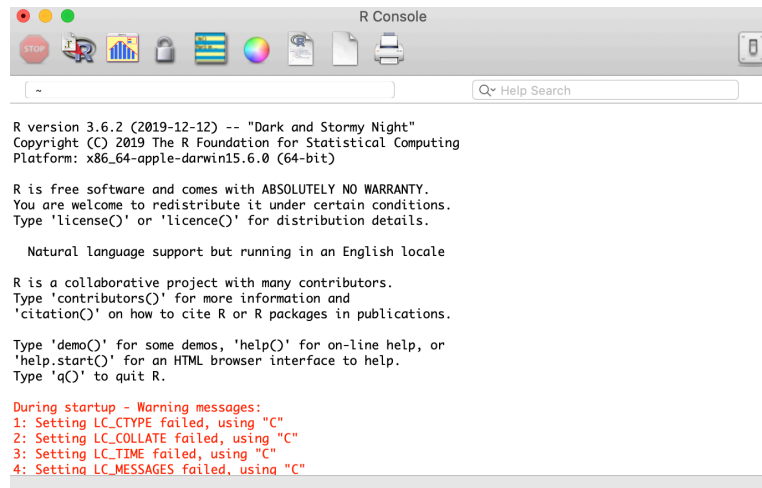


Figure 4.1. R console

R studio is an integrated development environment (IDE) for R, with a console, syntax-highlighting editor that supports direct code execution, and tools for plotting, history, debugging and workspace management [4.6.].

All the data treatment, analysis, plotting, and forecasting will be coded with R using R Studio environment. The whole code can be found in Annex 3

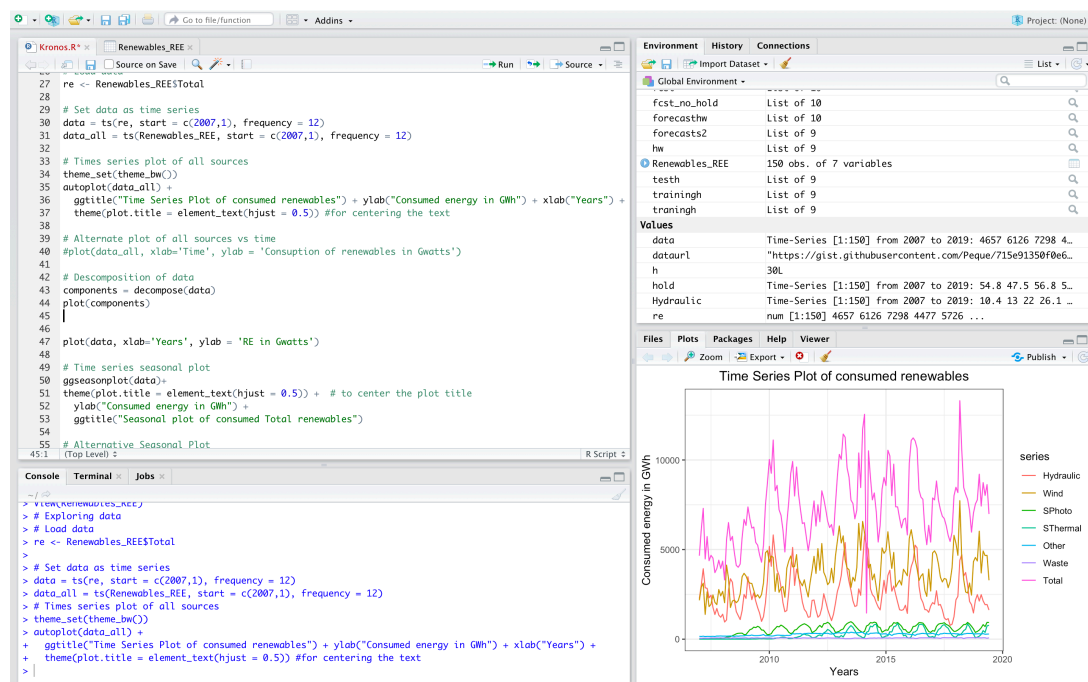


Figure 4.2. R Studio environment

4.3. Dataset

The dataset used is from **REE** (*Red Eléctrica de España*) [4.7.]

The whole dataset can be found in Annex 1 of this work. The data consists of consumed electricity from renewables at a national level (Spain). The frequency of the data is monthly, which means the total amount of renewable electricity consumed every month (GWh/Month). The dataset is classified by 6 different renewable energy sources; Hydraulic, Wind, Solar photovoltaic, Solar thermal, Waste and Other.

The time span of the data available is from January 2007 to December 2019, which means there are 144 registers for every energy source, each register corresponding to one month.

4.4. Data Treatment

Before stating the analysis, it is important to prepare the environment in order to have all the functions needed available. For that, the following packages are downloaded and loaded into R Studio environment;

```
1
2 # load packages
3 library('ggplot2')
4 library('forecast')
5 library('tseries')
6 library(readr)
7 library(tsibble) #tsibble for time series based on tidy principles
8 library(fable) #for forecasting based on tidy principles
9 library(ggfortify) #for plotting timeseries
10 library(forecast) #for forecast function
```

Figure 4.3. R Packages needed for the analysis

A package in R is a set of mathematical functions preprogramed that can be used by calling the name of the function.

Once all the packages are installed correctly and the data is downloaded from the source (REE), this must be treated to make suitable and understandable for R software.

After cleaning the data and loading it to the software, the plot of the general data is as shown in the figure below (see figure 4.4.), where the consumed renewable electricity is plotted in a time series form for the renewable sources analyzed.

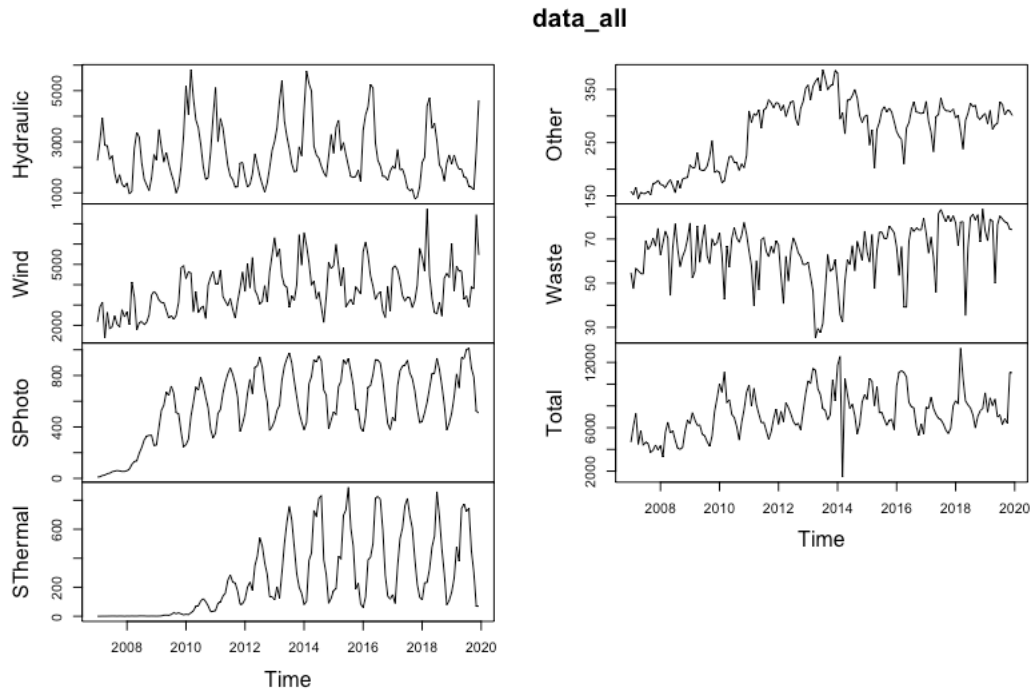


Figure 4.4. Plot of all the data by source (Renewable electricity consumed by source)

The plot illustrates the evolution of consumed electricity from different renewable energy sources over time; from January 2007 to December 2019. The plot is represented for Hydraulic, Wind, Solar Photovoltaic, Solar Thermal, Other renewables, waste renewables and the total of all these renewables combined.

To compare the real magnitude of all the sources, figure 4.5 is plotted for all renewable sources over the same scale.

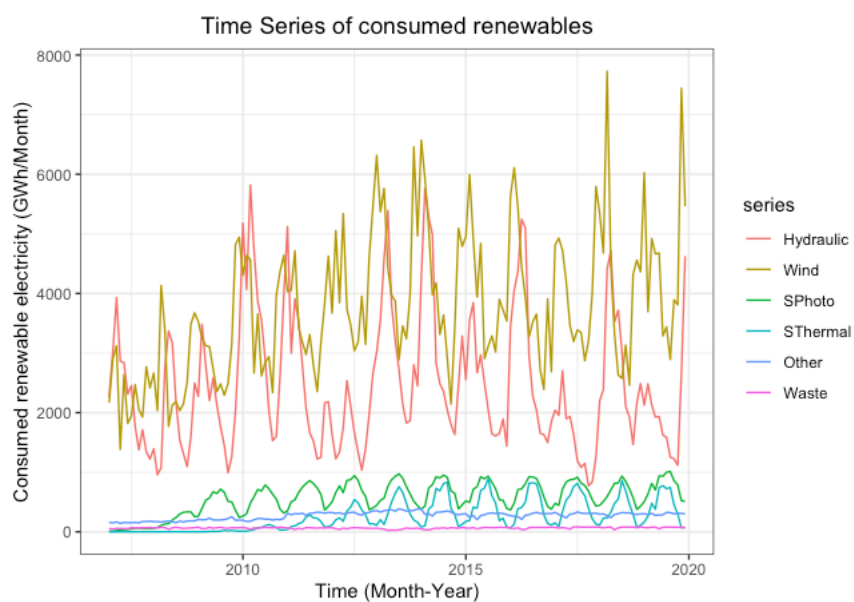


Figure 4.5. Plot of all the data by source

As observed in figure 4.5, Hydraulic and Wind sources are far over the other renewable sources.

In the next sections, the time series analysis will be made for Hydraulic, Wind, Solar Photovoltaic and Solar Thermal renewable sources as these are the most relevant in comparison to “Other renewable sources” and waste renewables. Although the plots for “Other renewable sources” and waste renewables can be found in Annex 2.

5. TIME SERIES ANALYSIS OF RENEWABLE SOURCES

In the following section, the analysis of data will be performed for the following energy sources; Hydraulic, Wind, Solar Photovoltaic and Solar Thermal power. Waste and other renewables are irrelevant in comparison to these main sources and will not be included in the analysis.

Waste renewables contains fossil derived materials such as plastics. It also contains biogenic materials such as paper, card and food waste.

Other renewables such as geothermal, biomass or marine also contribute to the generation of electricity but in very small quantity. Electricity consumed from these sources are negligible and will not be included in the analysis in this section

5.1. Hydraulic

Regarding the decomposition plot of Hydraulic electricity; the consumption of renewable electricity from hydraulic source has been fluctuating over time, with a clear pattern in seasonality but not in trend.

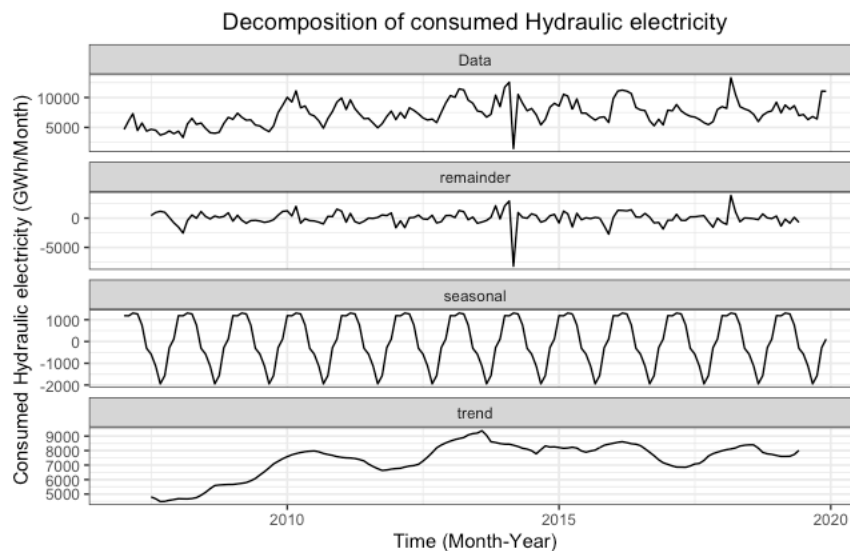


Figure 5.1. Decomposition of consumed Hydraulic energy

5.1.1. Trend of Hydraulic energy

The trend for Hydraulic energy does not have a clear pattern to it. As shown in figure 5.1, it has been fluctuating over the years with the lowest points at 2012 and 2017, and the highest at 2010 and 2013.

5.1.2. Seasonality of Hydraulic energy

The seasonality of Hydraulic source has a clear pattern inherent to it (see seasonal plot in figure 5.2.). The seasonal plot represents the data for the same month of the year shown by all the years analyzed (January 2007 to December 2019).

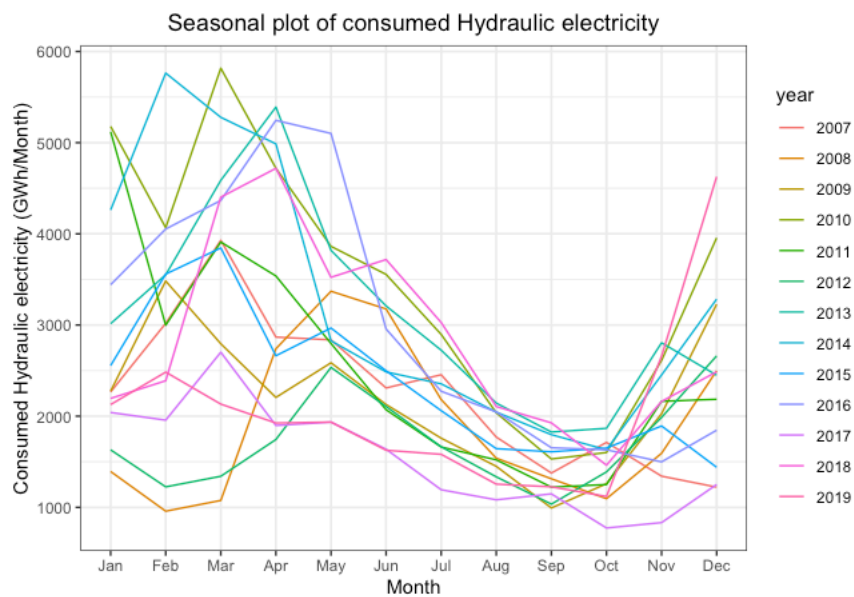


Figure 5.2. Seasonal plot of Hydraulic energy

From the plot, it can be observed that generally; the months with the highest production and consumption of Hydraulic electricity are around February, March and May (Spring). Then it decreases from June with the lowest at September – October (Autumn). This is due to the natural flow of rivers during the year. The flow of rivers is much higher in spring and at its lowest in autumn. This natural phenomenon translates directly to a greater Hydraulic energy generation and consumption in spring and lower generation and consumption in autumn.

5.2. Wind

The decomposition of the data for wind energy is displayed in the plot in figure 5.3. As it can be noticed, the seasonality is apparent while the trend is overall increase in the recent years.

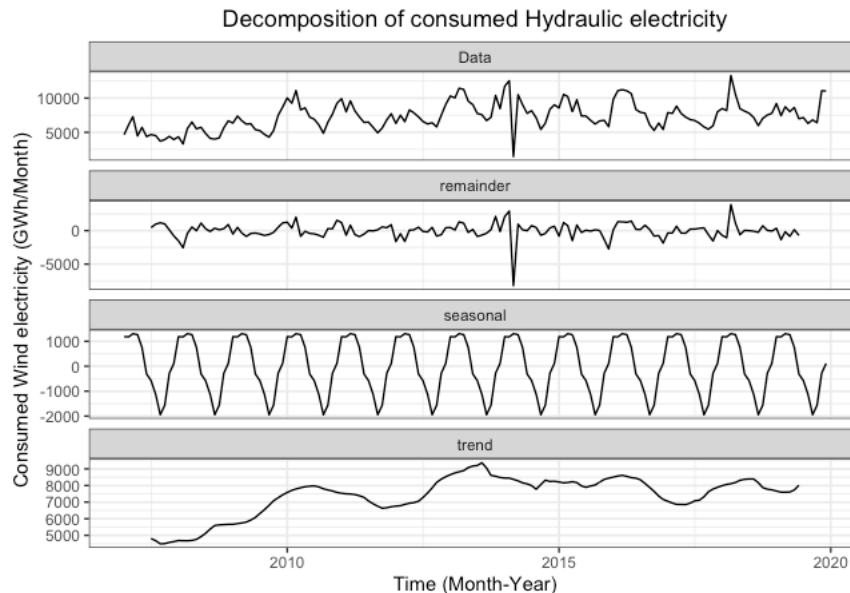


Figure 5.3. Decomposition of consumed Wind energy

5.2.1. Trend of wind energy

The increasing trend of the consumption of wind energy is very noticeable especially from 2007 – 2014. From 2014 – 2019 there has been no increase in the trend, but a small fluctuation is apparent.

5.2.2. Seasonality of wind energy

For further analysis of the seasonality of wind energy, it is relevant to plot the seasonality graph; for that the data for consumed wind energy for the same month of the year represented for all the years analyzed (January 2007 to December 2019)

As seen in the seasonal plot in figure 5.4, the generation of wind energy is very high in the months of January to April and very low from June to September. This is also directly correlated to the Spanish weather, as generally winds are very prominent in autumn and winter than in summer.

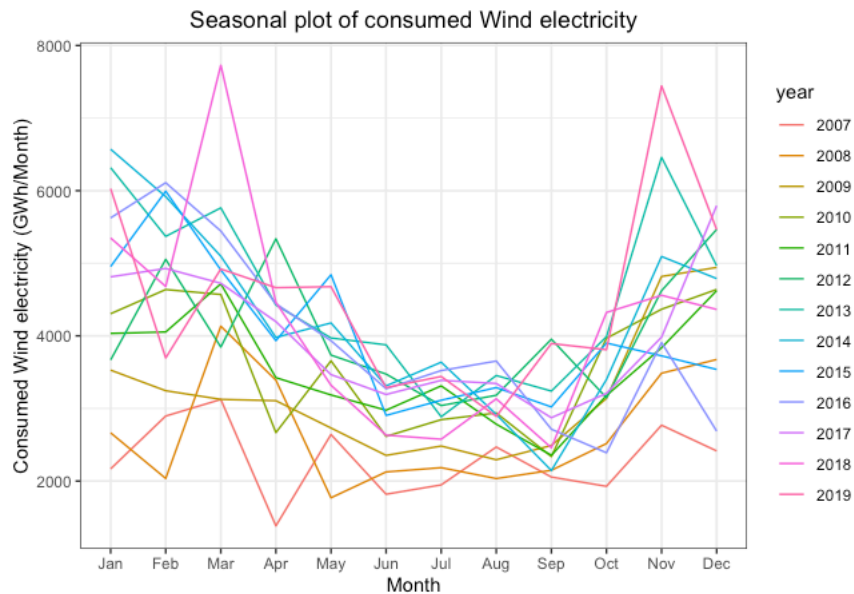


Figure 5.4. Seasonal plot of Wind energy

5.3. Solar Photovoltaic

The decomposition of the data for solar photovoltaic energy is displayed in the plot in figure 5.5. As it can be noticed, the seasonality is apparent following a very specific pattern which repeats itself every year. The overall trend is an increase since 2007 although it has been quite steady in the recent years with a slight decrease in 2017.

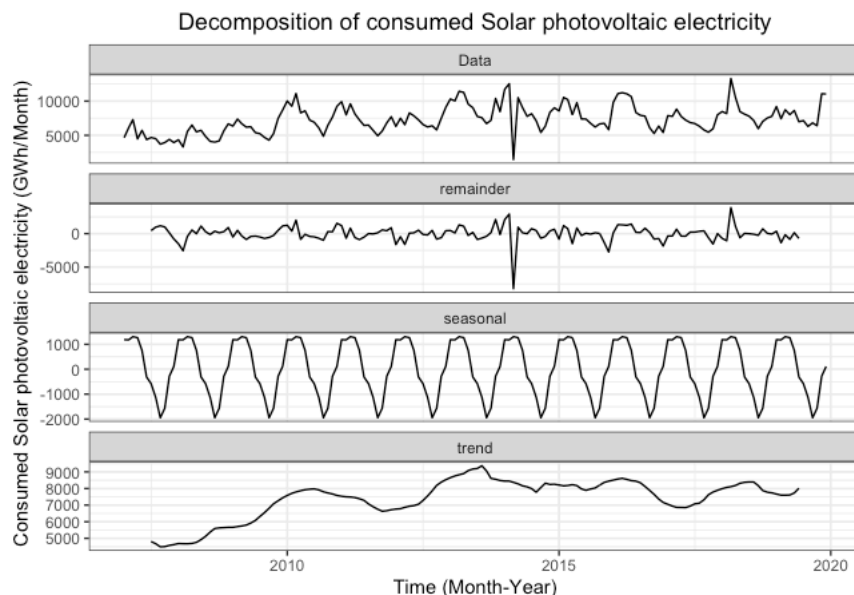


Figure 5.5. Decomposition of consumed Solar Photovoltaic energy

5.3.1. Trend of solar photovoltaic energy

The trend of solar photovoltaic is a year over year growth, it is one of the renewable energies with the highest a growth in investment each year. This translates to the generation of more electricity from this source which in term translates to a major consumption of higher photovoltaic electricity.

5.3.2. Seasonality of Photovoltaic energy

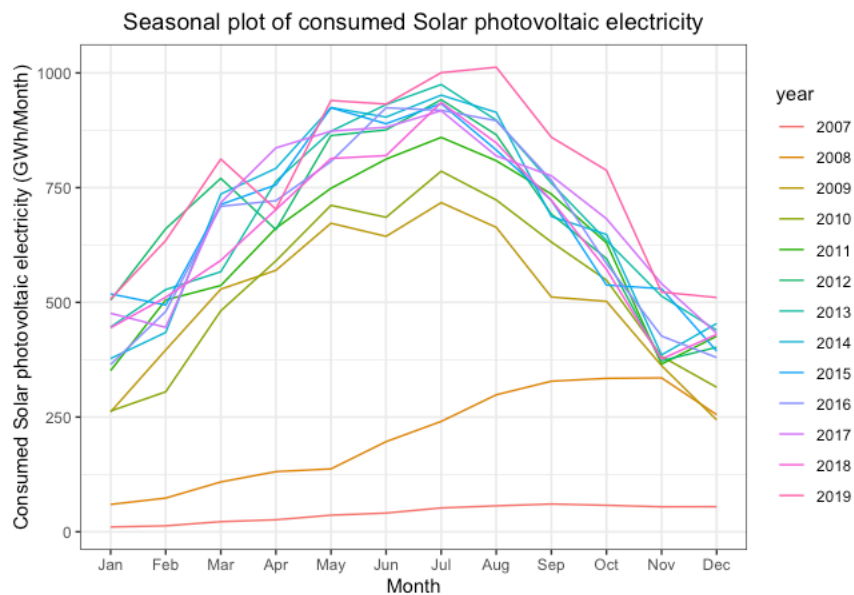


Figure 5.6. Seasonal plot of consumed solar photovoltaic energy

As observed in the seasonal plot; solar photovoltaic electric generation is higher in sunny months; aproximately from April to Septembre, with the most highest values in summer. Regarding the plot; the values of consumed Photovoltaic electricity is much higher in recent years than in 2007 – 2008. This relects the interest in investing in Solar energy as one of the main sources for thr future.

Analyzing all the seasonal plot of Hydraulic, Wind and Photovoltaic, it is important to notice that; they are complementary sources. As one source decreases over the year , the other two increase and vice-versa. This observation means a whole energy system based just on renewable sources is possible thougout the whole year if done and implemeted correctly.

5.4. Solar Thermal Power

For the scope of this work, just solar thermal power is considered. This is just the electricity generated and consumed from solar thermal plants. Heat used from solar thermal will not be considered. The decomposition of the data for solar thermal power is displayed in figure 5.7.

The seasonal part of the decomposition shows a wave pattern which is very similar solar photovoltaic. Both of these rely on the sun as main source for electricity generation.

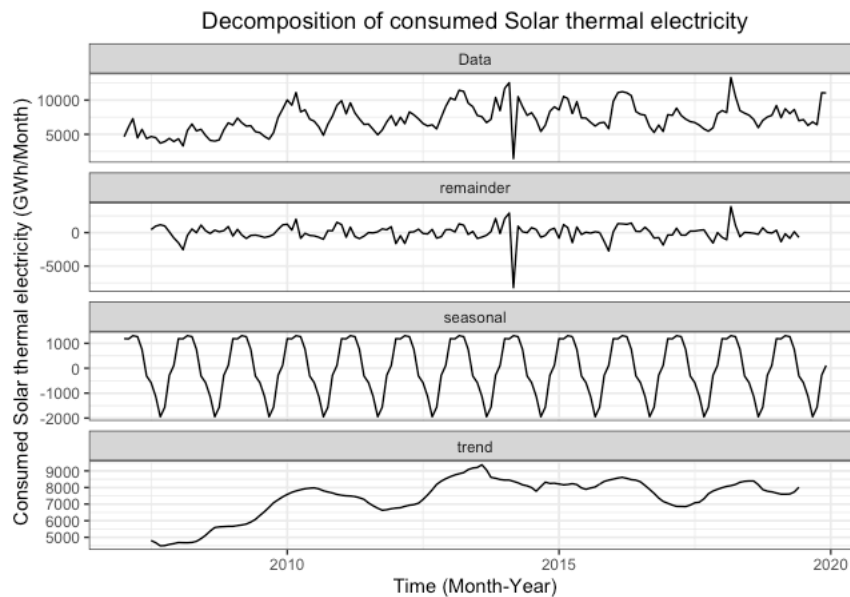


Figure 5.7. Decomposition of consumed Solar thermal energy

5.4.1. Trend of solar thermal

As in the case of solar photovoltaic, solar thermal power has also been gaining traction since 2007.

It is very apparent that the highest months of production and consumption of solar electricity is in summer. It is also noticeable between 2007 – 2011 the production and consumption were very low.

On the other hand, since 2014 the consumption from this source has been very high. As in the case of solar photovoltaic, solar thermal has been receiving a lot of investment in the recent years, which translates to this increase in the production and consumption of this energy source.

5.4.2. Seasonal plot of solar thermal

The seasonal plot for solar thermal energy is as following:

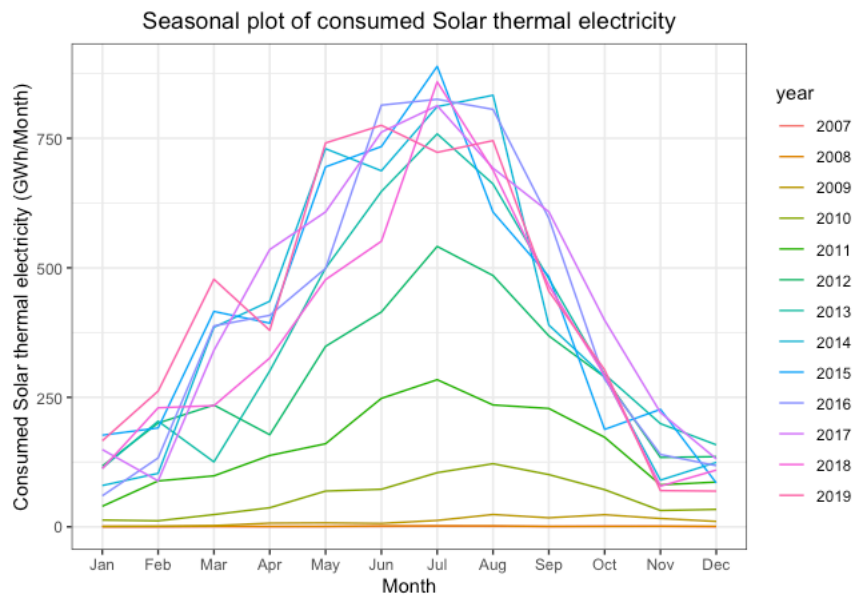


Figure 5.8. Seasonal plot of consumed Thermal energy

For solar thermal, it is even more apparent the difference between the electricity produced in sunny months compared to cold months. Regarding the seasonal plot, it is noticeable the great increase between 2009, 2010, 2011 and 2012 where energy consumption took a huge leap every year. The production and consumption of electricity have then been similar for the rest of the years.

5.4.3. Overall trend of analyzed renewable energy sources

The following plot is the decomposition of all renewable sources with waste and other renewable electricity included (see figure 5.9).

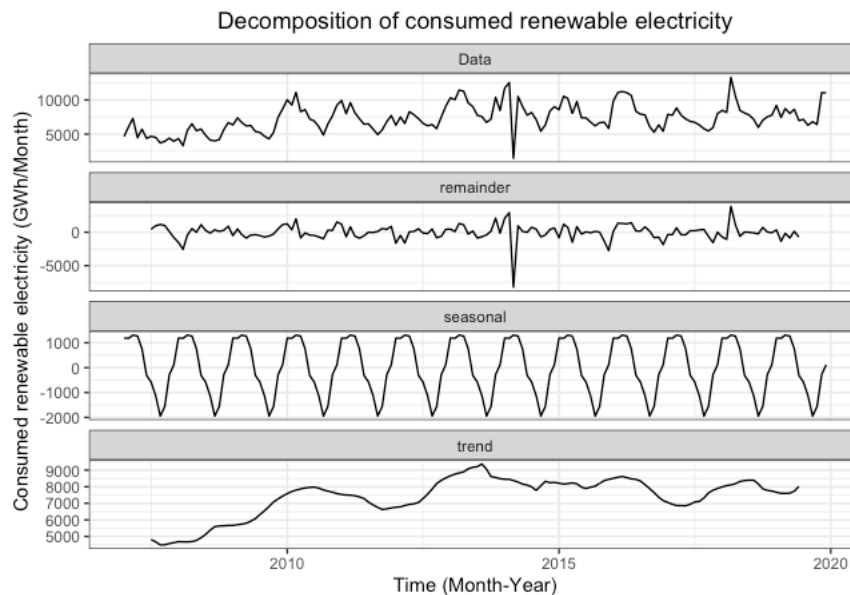


Figure 5.9. Decomposition of all consumed renewable electricity

The total trend is a wave fluctuation over years. 2007- 2010 were years of growth for renewable sources. In 2012 there was a local minimum and another one in 2017. All time maximum was around 2013 – 2014 for the range of data analyzed in this work.

The relevant minimum production in 2012 was due to a change in the legislation implemented by Spanish government in 2011. The *Real Decreto Ley 12/2011*, from August 26. The regional laws in the field of the public hydraulic system were modified. This is reflected in the in the chart from figure 5.9.

There is also another law that hindered the production of energy from renewable sources, the *Real Decreto Ley 1/2012*, from January 27, which eliminates the procedures of remuneration and economic incentives for new facilities for the production of electricity from cogeneration, biomass, biogas, hydraulics and waste. Years later, these laws were eliminated in order to incentive the generation from renewable sources.

6. MODEL ELECTION, OPTIMAZATION AND VALIDATION

6.1. Model Election

There are a lot of models when it comes to time series analyses. Two of the most important and popular ones are ARIMA Models and Exponential Smoothing models (also known as Holt Winters). These are the two models that will be used for this work.

6.1.1. ARIMA Model

A popular and widely used statistical method for time series forecasting is the ARIMA model.

ARIMA is an acronym that stands for **Auto-Regressive Integrated Moving Average**. It is a statistical model for analyzing and forecasting time series data that captures a suite of different standard temporal structures in time series data.

This acronym is descriptive, capturing the key aspects of the model itself. Briefly, they are:

- **AR:** Autoregression. A model that uses the dependent relationship between an observation and some number of lagged observations.
- **I:** Integrated. The use of differencing of raw observations (e.g. subtracting an observation from another observation at the previous time step) in order to make the time series stationary.
- **MA:** Moving Average. A model that uses the dependency between an observation and a residual error from a moving average model applied to lagged observations.

Each of these components are explicitly specified in the model as a parameter. A standard notation is used for $ARIMA(p,d,q)$. Where the parameters are substituted with integer values to quickly indicate the specific ARIMA model being used.

The parameters of the ARIMA model are defined as follows:

p: The number of lag observations included in the model, also called the lag order.

d: The number of times that the raw observations are differenced, also called the degree of differencing.

q: The size of the moving average window, also called the order of moving average.

A linear regression model is constructed including the specified number and type of terms, and the data is prepared by a degree of differencing in order to make it stationary, i.e. to remove trend and seasonal structures that negatively affect the regression model.

A value of 0 can be used as parameter, which indicates that the particular element is not used in the model. This way, the ARIMA model can be configured to perform the function of an ARMA model, and even a simple AR, I, or MA model. [6.1.]

Adopting an ARIMA model for a time series assumes that the underlying process that generated the observations is an ARIMA process. This may seem obvious but helps to motivate the need to confirm the assumptions of the model in the raw observations and in the residual errors of forecasts from the model.

Mathematically, the Auto-Regression (AR) part it is modelled as following; AR(p) [6.2.]:

$$Y_t = \phi_0 + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + \alpha_t \quad (\text{equation 1})$$

The moving average part is modelled as following; MA(q):

$$Y_t = \mu + \alpha_t + \theta_1 \alpha_{t-1} + \theta_2 \alpha_{t-2} + \cdots + \theta_q \alpha_{t-q} \quad (\text{equation 2})$$

The whole ARIMA model is defined as:

$$Y_t = -(\Delta^d Y_t - Y_t) + \phi_0 + \sum_{i=1}^p \phi_i \Delta^d Y_{t-1} - \sum_{i=1}^q \theta_i \alpha_{t-i} + \alpha_t \quad (\text{equation 3})$$

6.1.2. Exponential Smoothing Models (Holt Winters)

Holt-Winters is a model of time series behavior. Holt-Winters is a way to model three aspects of the time series: a typical value (average), a slope (trend) over time, and a cyclical repeating pattern (seasonality). Holt-Winters uses exponential smoothing to encode lots of values from the past and use them to predict “typical” values for the present and future.

Holt-Winters is also called triple exponential smoothing. The model predicts a current or future value by computing the combined effects of these three influences. The model requires several parameters: one for each smoothing (α , β , γ), the length of a season, and the number of periods in a season. [6.3.]

Mathematically it is expressed as following:

$$\hat{x} = \lambda_0 x_t + \lambda_1 x_{t-1} + \dots + \lambda_n x_{t-n} \quad (\text{equation 4})$$

Where $\lambda_i = \alpha^i$ with $0 < \alpha < 1$ [6.4.] [6.5.]

6.1.3. ARIMA vs Holt Winters packages in R Software

Both ARIMA and Holt Winters use the same library in R which is **forecast** [6.6.]. The code used for the forecast are shown in the following figures;

```
74 #Model testing Arima
75 training = window(data, end=c(2016,12))
76 test = window(data, start=c(2017,1))
77 training %>% ets %>% forecast(h=length(test)) -> fc
78 plot(fc,type="l", lty=2, main= "Hydraulic energy forecast ARIMA",
79      xlab='Years', ylab = 'Consumed energy in GWh')
80 lines(test, type="l", lty=2)
```

Figure 6.1. Code for forecasting with ARIMA

```
82 #Model testing Holt Winters
83 training = window(data, end=c(2016,12))
84 trainingh = HoltWinters(training)
85 test = window(data, start=c(2017,1))
86 forecast(trainingh, h=length(test)) -> fc
87 plot(fc,type="l", lty=2, main= "Hydraulic energy forecast HoltWinters",
88      xlab='Years', ylab = 'Consumed energy in GWh')
89 lines(test, type="l", lty=2)
```

Figure 6.2. Code for forecasting with Holt Winters

After comparing both models in R, the conclusion is; Holt Winters captures the trend and seasonality and then extrapolates for future forecasting. This makes it preferable for forecasting the production of electricity from renewables long term as the most important feature of the decomposition of a time series data is the trend when it comes to long term. ARIMA on the other hand is a very good model when it comes to tuning parameters and building a model that minimizes the error between the actual data point and the forecast data point. For this reason, ARIMA will be used for forecasting in a near future (24 months) while Holt Winters (Triple exponential smoothing) will be used to forecast the consumption of electricity by renewables in the next 10 years.

Figures 6.3. and 6.4. show forecasts for Hydraulic electricity made with Arima model for 10 years (2020-2030) and the same forecast with Holt Winters model. It is noticeable that

the trend and seasonality are not well captured when the time stamp is very large, although ARIMA does a good job for a short period of time capturing the pattern in the data.

In figure 6.3, it is noticeable that ARIMA model is very inaccurate when the prediction is performed long term.

Holt Winters on the other hand does a very good job capturing the seasonality and trend of the data and extrapolates for future prediction (see figure 6.4.).

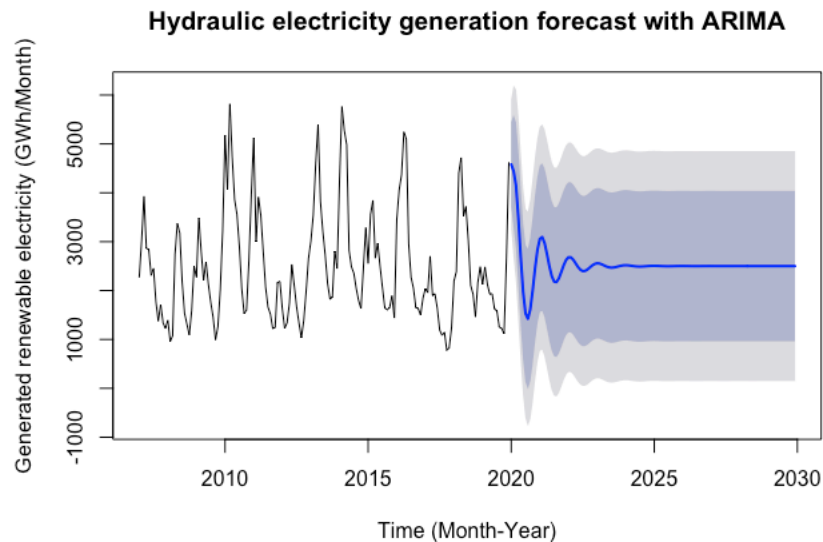


Figure 6.3. 10 years forecast with ARIMA

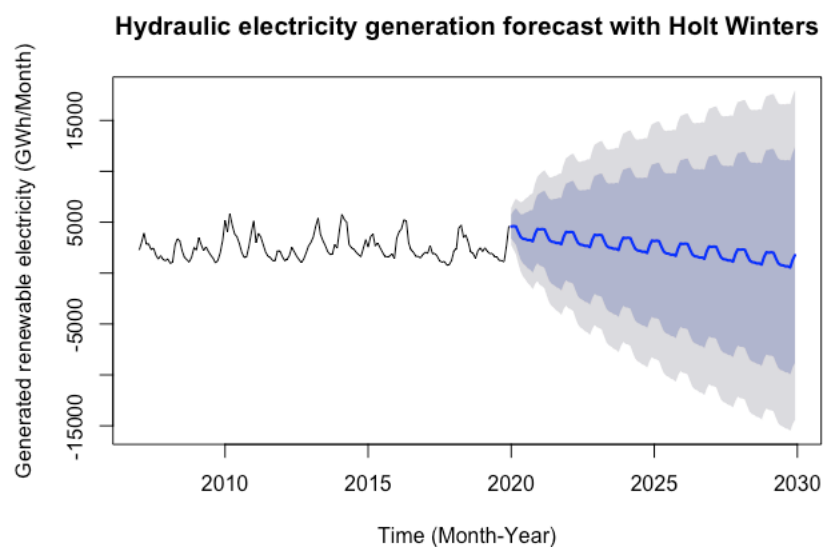


Figure 6.4. 10 years forecast with Holt Winters

6.2. Model Optimization

The optimization of the model is done automatically by the functions included in the R software packages downloaded for the forecast. The process of optimization is out of the scope of this work.

The optimized parameters for both models are the following (see figure 6.5.).

```
> autoarima
Series: data
ARIMA(2,0,3) with non-zero mean

Coefficients:
      ar1      ar2      ma1      ma2      ma3      mean
    1.5582 -0.8193 -0.6938  0.1410  0.2021 2500.4955
s.e.  0.0886  0.0817  0.1276  0.1045  0.1129  131.8385

sigma^2 estimated as 455541:  log likelihood=-1235.38
AIC=2484.76  AICc=2485.52  BIC=2506.11
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

Call:
HoltWinters(x = data)

Smoothing parameters:
alpha: 0.7988529
beta : 0
gamma: 1

Coefficients:
      [,1]
a  3865.22065
b   -23.83433
s1   735.64541
s2   798.68696
s3   784.86294
s4   253.50397
s5  -204.59832
s6  -356.86193
s7  -358.77254
s8  -438.86319
s9  -397.06745
s10 -507.49632
s11  252.89918
s12  761.30035
```

Figure 6.5. Parameters of ARIMA model

Note: The model validation and optimized parameters for both models (ARIMA and Holt Winters) for the rest of renewable energy sources are found in Annex 2 (Forecast parameters)

6.3. Model validation

Figures 6.7 and 6.8 show the real data overlapped with the forecast made for the same period using both models

In this case, the data was truncated until December of 2016, so each model has to predict the consumed electricity from the renewable source from January 2017 to December 2019. Then the prediction is superposed over the real data to the accuracy. The results are shown in figures 6.7 and 6.8.

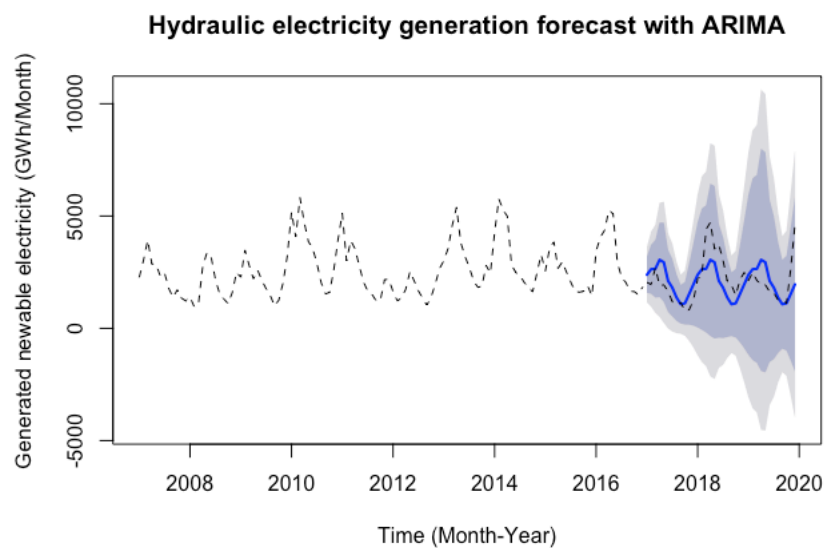


Figure 6.7. ARIMA model validation

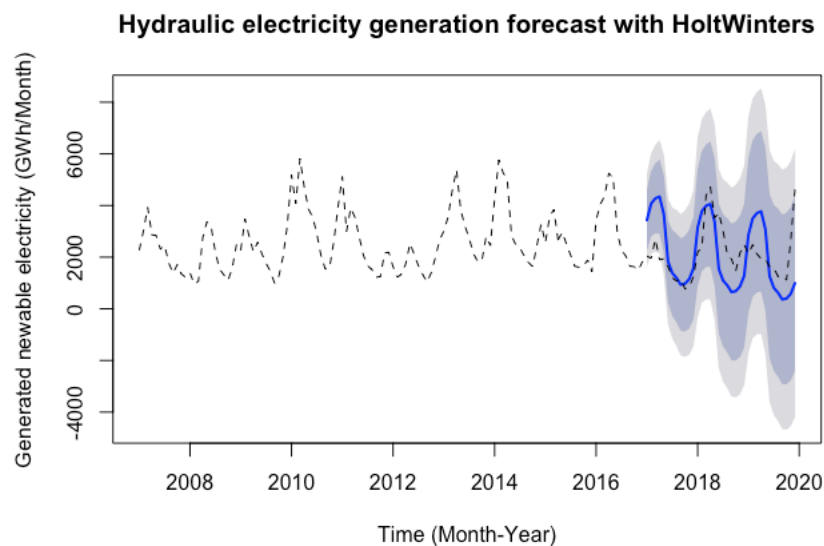


Figure 6.8. Holt Winters model validation

Taking into account that both models are using optimized parameters, it is noticeable that the ARIMA model is more accurate in capturing the patterns in the data while Holt Winters (Exponential Smoothing) seems to smoothen the overall pattern in favor of capturing the seasonality and trend.

For this reason, the analysis in the next section will be done using both models. ARIMA for short term forecast (24 months) and Holt Winters for long term forecast (10 years).

This comparison is done for all the other renewable energy sources. The plots are found in Annex 2.

7. FUTURE SCENARIO; TARGETS AND FORECASTS

This section is dedicated to the analysis of target established by Spain for 2030. The prediction will be compared to the forecasts made by the models in the previous section.

This is comparing the objective scenario established by *Plan Nacional Integrado de Energía y Clima* to the trend scenario calculated mathematically in the previous section.

But first, it is interesting to analyze the global targets established for renewable sources. The main target for 2030 worldwide is established by one of the Sustainable development goals; goal number 7 (SDG 7)

Nationally, the goals for 2030 are established by the *Plan Nacional Integrado de Energía y Clima*.

7.1. Targets

The targets established by Sustainable development goals; goal number 7 (SDG 7) and the *Plan Nacional Integrado de Energía y Clima* are the following.

7.1.1. Worldwide (Sustainable development Goals)

SDG agreed on some targets for 2030 agenda, in which the goal number 7 (SDG 7) is to Ensure access to affordable, reliable, sustainable and modern energy for all. As most of the forecast in this work has been done for 2030. The targets of SDG 7 are [7.1.]:

- By 2030, ensure universal access to affordable, reliable and modern energy services
- By 2030, increase substantially the share of renewable energy in the global energy mix
- By 2030, double the global rate of improvement in energy efficiency
- By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology
- By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least

developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support.

7.1.2. Spain (*Plan Nacional Integrado de Energía y Clima*)

In Spain, the targets are established by *Instituto para la Diversificación y Ahorro de la Energía (IDAE)* which is part of *Ministerio para la Transición Ecológica* regarding energy production and energy consumption in 2030.

Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030: is the official document presented by IDAE which defines the objectives of reducing greenhouse gas emissions, renewable energy penetration and energy efficiency. [7.2.]

In their official document (***PNIEC***), they state that Spain must accomplish the target of European Commission. On 28 November 2018, the roadmap was updated towards a systematic decarbonization of the economy with the intention of converting the European Union into carbon neutral in 2050. (*Comunicación de la Comisión, COM/2018/773 final*) The mayor targets set by ***Plan Nacional Integrado de Energía y Clima*** to be accomplished by 2030 in Spain are the following: [7.3.] [7.4.]

- Primary energy consumption to be reduced by 39.6% in 2030 relative to EU trend scenario.
- Primary energy intensity (the amount of primary energy consumed in the country, divided by GDP) to be reduced by 37% between 2015-2030.
- Energy dependence abroad to be decreased 15 percentage points, from 74% in 2017 to 59% in 2030, which in addition to strengthening national energy security will have a very favorable impact on our country's trade balance.
- The import of fossil fuels (coal, oil and gas) between the present and the year 2030 to be decreased by 29% in physical units. This helps that in the objective scenario more than 75,000 million euros accumulated from fossil fuel imports compared to the trend scenario are saved.
- The presence of renewable energies in final energy use in the economy as a whole to reach 42% in 2030 (from the current 17%). This value is obtained as a combined result of the presence of electric renewables, thermal renewables in the different sectors of the economy, and as a consequence of the decrease in the amount of

final energy due to the implementation of the savings and efficiency programs provided for in the Plan.

- **Plan Nacional Integrado de Energía y Clima** for 2030 predicts a total power installed of 157 GW in the power sector, of which 50 GW will be wind power; 37 GW photovoltaic solar; 27 GW combined gas cycles; 16 GW hydraulic; 8 GW pumping; 7 GW solar thermoelectric; and 3 GW of nuclear, as well as smaller amounts of other technologies. (see table 7.1.).

Generación eléctrica bruta del Escenario Objetivo* (GWh)				
Años	2015	2020	2025	2030
Eólica (terrestre y marina)	49.325	60.670	92.926	119.520
Solar fotovoltaica	8.302	16.304	39.055	70.491
Solar termoelectrica	5.557	5.608	14.322	23.170
Hidráulica	28.140	28.288	28.323	28.351
Almacenamiento	3.228	4.594	5.888	11.960
Biogás	743	813	1.009	1.204
Geotermia		0	94	188
Energías del mar		0	57	113
Carbón	52.281	33.160	7.777	0
Ciclo combinado	28.187	29.291	23.284	32.725
Cogeneración carbón	395	78	0	0
Cogeneración gas	24.311	22.382	17.408	14.197
Cogeneración productos petrolíferos	3.458	2.463	1.767	982
Otros	216	2.563	1.872	1.769
Fuel/Gas	13.783	10.141	7.606	5.071
Cogeneración renovable	1.127	988	1.058	1.126
Biomasa	3.126	4.757	6.165	10.031
Cogeneración con residuos	192	160	122	84
Residuos sólidos urbanos	1.344	918	799	355
Nuclear	57.196	58.039	58.039	24.952
Total	280.911	281.219	307.570	346.290

Fuente: Ministerio para la Transición Ecológica y el Reto Demográfico, 2019

Table 7.1. Renewable energy target 2030. Source: [Ministerio para la transición ecológica]

The total investment that will mobilize the **Plan Nacional Integrado de Energía y Clima 2021-2030**, is estimated at 236,000 million euros over the decade. 80% of the investments will be made by the private sector and 20% by the public sector.

In this sense, it is expected to achieve a presence of renewable energies in 2030 on the final use of energy in 2030 due to the large planned investment in electric and thermal renewable energies, and the notable reduction in final energy consumption as a result of the programs, savings and efficiency measures in all sectors of the economy.

Finally, it should be noted that the impetus to the deployment of renewable energies, distributed generation and energy efficiency promoted by the *Plan Nacional Integrado de Energía y Clima* is characterized by being anchored to the territory. Consequently, its execution will generate significant investment and employment opportunities for the regions of Spain that currently have higher unemployment rates and lower levels of economic development.

7.2. Forecast and prediction for future energy scenario

This section is dedicated to the generation and analyses of forecasts generated by ARIMA and Holt Winters. The prediction will be made for near future (24 months) with ARIMA and long term (2020-2030) with Holt Winters. The forecasts will then be compared to the objective targets established by the *Plan Nacional Integrado de Energía y Clima (PNIIEC)* to compare feasibility of these targets compared to the analysis based solely on the trend predicted by mathematical models. The studies will be done for each of the following energy sources; Hydraulic, Wind, Solar Photovoltaic and Solar Thermal power. Waste and other renewable sources will not be contemplated in this section as they are negligible in comparison to the main sources mentioned previously.

The objective target by *PNIIEC* will be superposed on the forecast plot for long term (Holt Winters). The objective is to see how the prediction compares to the objective target from 2020 to 2030.

7.2.1. Hydraulic

The plot from figure 7.1 shows the prediction of Hydraulic energy source for the next 2 years.

Hydraulic energy for the near future until 2021 seems to stabilize; there is no mayor increase or decrease observed. ARIMA model captures the fluctuations in recent years and predicts consumption of hydraulic power close to the consumption of recent years.

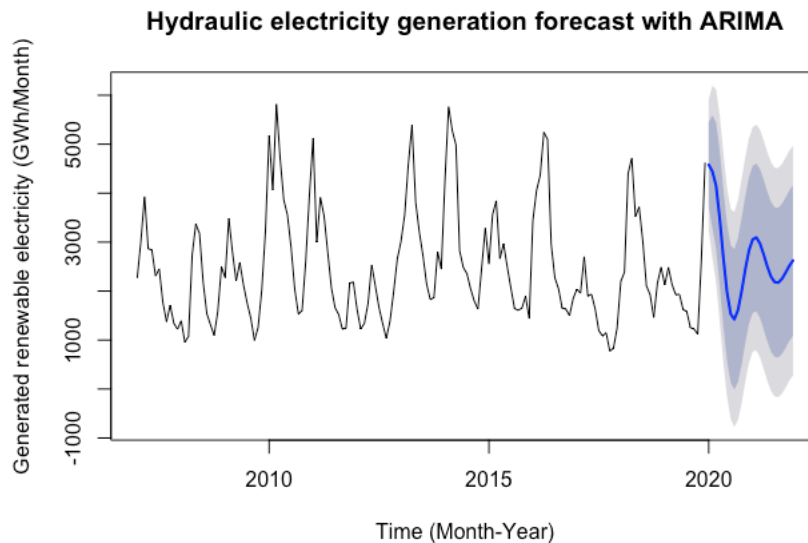


Figure 7.1. 18 months Arima forecast

In the long term however, the prediction from Holt Winters is a decrease in the consumption of hydraulic energy (see figure 7.2). This is because the general trend in recent years is a reduction in hydraulic energy consumption; hence this trend is captured by the model and extrapolated for the future prediction.

The prediction from **PNIEC** is just a 0,22% (28288 GWh/year in 2020 vs 28351 GWh/year in 2030). This is just a very small increase for hydraulic energy sources in a whole decade. Which means there is not any intention of investment in the hydraulic sector.

Regarding the forecast made with Holt Winters there is an actual decrease in the prediction for 2030, which makes sense as there has been a trend of decrease with hydraulic sources in the recent years. The prediction coincides with **PNIEC** forecast, which is a close to 0% increase in the coming decade.

Comparing both predictions, the one made by the statistical model is very close to the actual target of **PNIEC** both closely overlap as it seen in the plot from figure 7.2.

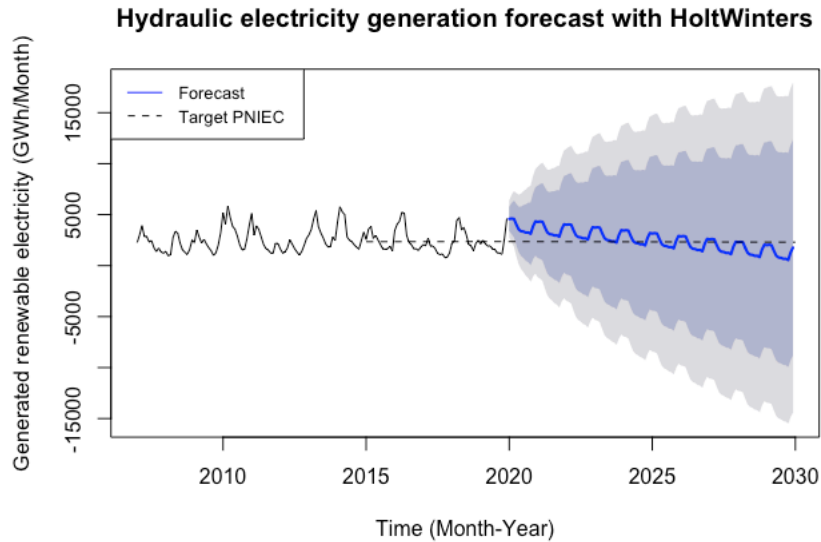


Figure 7.2. 10 years Holt Winters forecast

7.2.2. Wind

For wind energy, the consumption for the next 24 months (end of 2021) is quite similar to the consumption of 2018 and 2019 with a slight increase. The pattern of consumption per month has been captured quite well for the ARIMA prediction. The prediction seen the plot from figure 7.3 could be very close to the real consumption until 2022 if there is no mayor change in the legislation or wind power plants, which is very unlikely in the near future.

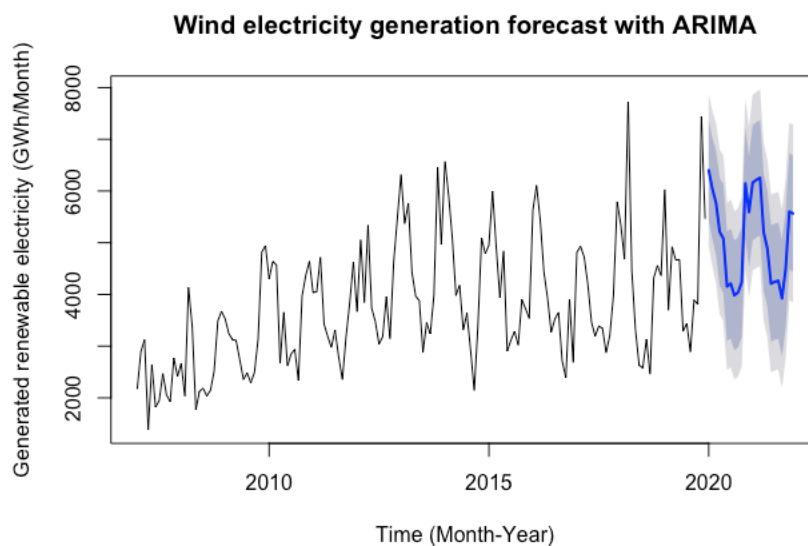


Figure 7.3. 18 months ARIMA forecast

Regarding the prediction for 10 years from Holt-Winters (triple exponential smoothing), the trend is an increase. It is a very noticeable increase as seen in the plot below (see figure 7.4). Even though there was a slight decrease around 2012-2014, the overall trend has been captured very well. The seasonality is also represented perfectly in the forecast. The seasonality in the forecast is represented without noise, as random noise is impossible to predict hence it is automatically removed by the model.

Comparing this forecast to the prediction by **PNIEC**, wind energy is supposed to increase from 60670 GWh/year in 2020 to 119520 GWh/year in 2030; which is an equivalent to 50% increase in the coming decade.

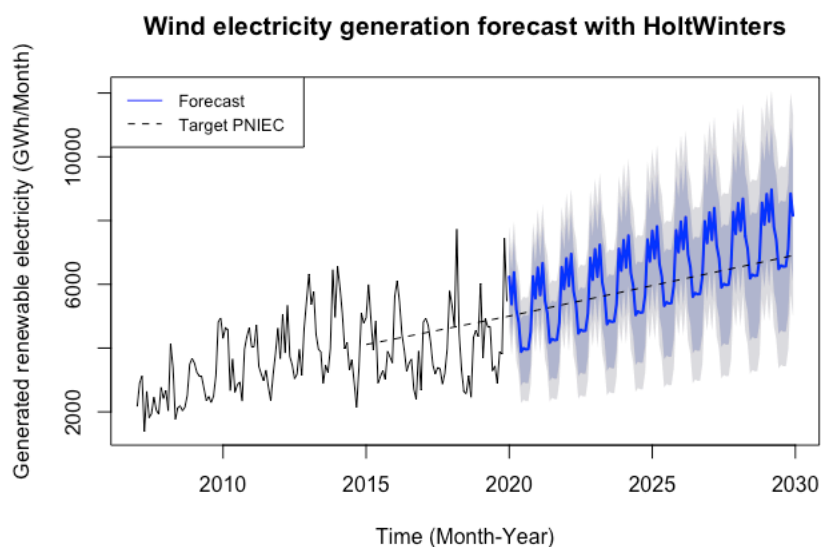


Figure 7.4 10 years Holt Winters forecast

Regarding the plot made by Holt Winters model, the prediction is very close to the established target in average. Although the model predicts a slightly higher increase in trend than the actual objective target.

This can be explained as the forecast made by the model takes into account the whole data since 2007 hence the forecast is based on this historical data. **PNIEC** on the other hand is an action plan that just takes into account this decade 2020-2030, this means there can be an intended change trend which will not be contemplated by the model.

7.2.3. Solar Photovoltaic

Forecast with ARIMA model for January 2020 to December 2021 is quite accurate for solar photovoltaic. The trend in increase is noticeable. The overall seasonality is well represented; with the highest consumption in summer months and lowest in winter. The 80% (gray) and 95% (light gray) confident level of prediction are quite close to the actual prediction, which means the model is very confident in the forecast.

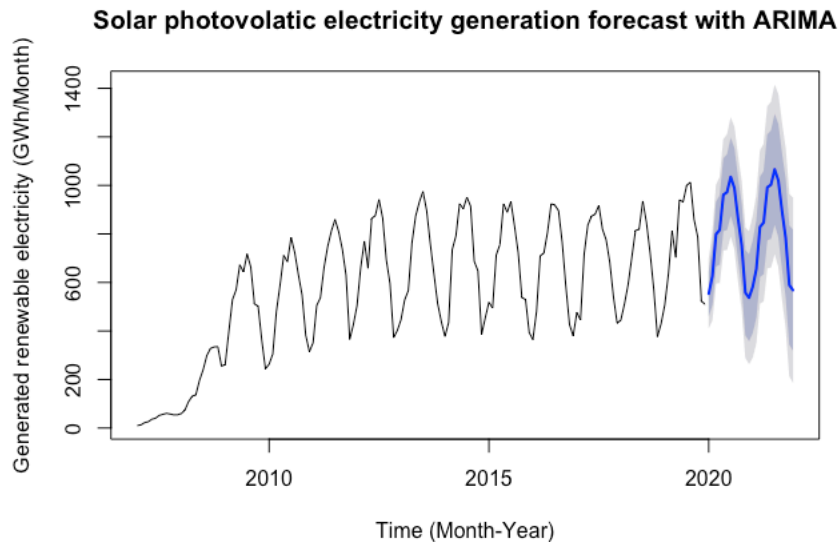


Figure 7.5. 18 months ARIMA forecast

Regarding the forecast with Holt Winters for 10 years, there is a very large increase in the trend of solar photovoltaic energy consumption. This makes sense because as analyzed earlier in this work, solar jointly with wind are the two energy sources in which there are being most investments. The forecast is basically the prolongation of this trend 10 years in the future taking into account the seasonality.

According to the target of **PNIEC**; generation of solar photovoltaic is set to grow from 16403 GWh/year to 70491 GWh/year in 2030 (see table 7.1). Which is an increase of 77% growth in the next decade. A huge increase as observed. In order to achieve this target, there will be a very big investment in the current decade to increase drastically the amount of energy produced by solar photovoltaic sources.

Regarding the forecast plot, it is seen that the objective target is far higher than the prediction made by the model. Although the objective target purposed by **PNIEC** in 2015 for 2020 is very inaccurate compared to the real data as seen in figure 7.6. Solar photovoltaic energy was supposed to have a very huge leap from 2015 to 2020 but that

was not the case. The real data shows the complete opposite as there has been no increase in the trend of solar photovoltaic energy since 2015. The model takes into account the fact and predicts a trend according to the historical data. **PNIEC** on the other hand sticks to the objective targets purposed in 2015. Which is very unlikely to be accomplished as the real consumption of energy in 2020 is far behind the target that was established.

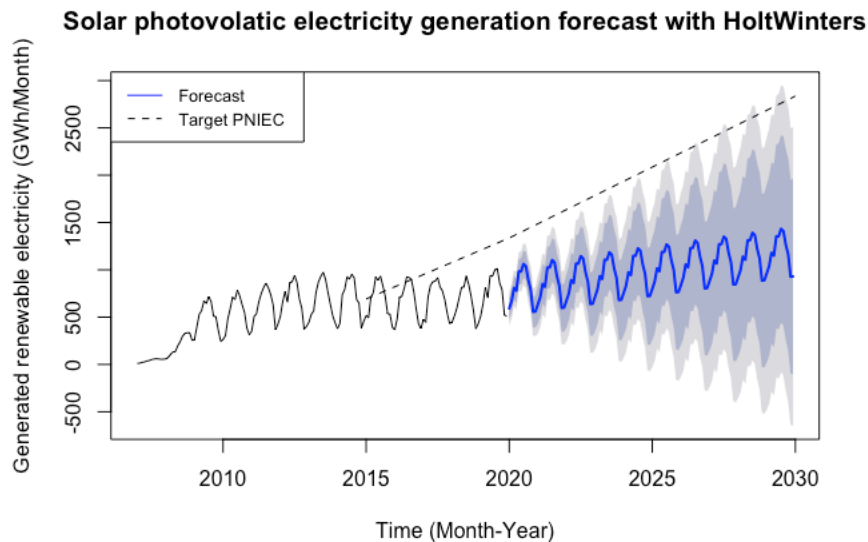


Figure 7.6. 10 years Holt Winters forecast

7.2.4. Solar Thermal

Forecast of solar thermal power with ARIMA model for 2021 is very accurate as in the case of solar photovoltaic. The trend in increase is noticeable and the overall seasonality is also well represented; with the highest consumption in sunny months and lowest in winter. As in the case of solar photovoltaic. The 80% and 95% confident level of prediction are very close to the actual prediction, meaning the model is very accurate (see figure 7.7.).

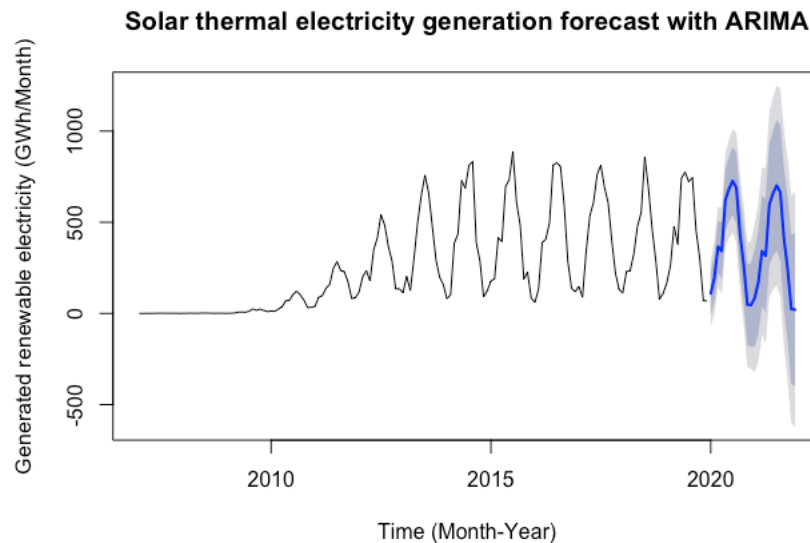


Figure 7.7. 18 months ARIMA forecast

Holt Winters model prediction for the next 10 years is a noticeable increase in the consumption of solar thermal power energy. There has been an increase in the trend of solar thermal energy consumption in the last years. The forecast is a prolongation of this trend 10 years in the future taking into account the seasonality and disregarding any noise or random disturbances in the data.

This great increase in trend for solar photovoltaic is due to the great quantity of power installed in 2008. With the changes in legislation in 2013-2014, solar thermal sector was hindered as there were still a lot of performance to be explored. Now with the withdrawal of the law, solar thermal is supposed to have a lot of traction in the future.

The prediction from **PNIEC** is an increase from the current consumption of 5608 GWh/year in 2020 to 23170 GWh/year in 2030; 76% increase in solar thermal production for the next decade.

As said for solar photovoltaic, this technology will also see a very big increase in investment by the end of this decade.

It is interesting to Notice how solar thermal power energy will change trend drastically from 2020 to 2025 to 2030 according to the plans of **PNIEC**. This is because new power plants will be built and start to produce energy in the coming decade.

Regarding the prediction plot (see figure 7.8.), this drastic increase in trend is not captured as there is no way to predict such a huge change.

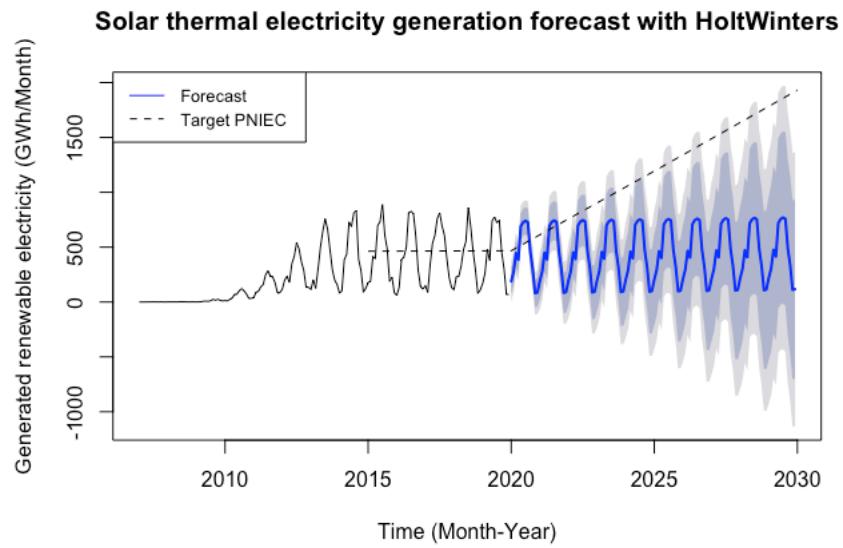


Figure 7.8. 10 years Holt Winters forecast

8. CONCLUSIONS

This is the final section of the project. In this section, the two main research questions will be answered taking into account all the analysis made until now.

8.1. Current situation of renewables

One of the objectives of this Project was to determine the role of renewables compared to non-renewable sources at a national level and worldwide.

This objective has been achieved. According to the evidences presented in this project, renewables has come a very long way since they started being implemented. Hydraulic has been for years the main renewable source worldwide and also in Spain. From early 2000s, other renewable sources started gaining traction; especially wind and solar sources. Since then, renewable energy consumption has been increasing year over year. The adoption and growth of renewables are still relatively small worldwide depending on the country. Generally, developed countries and the ones with large economy such as USA and China are the ones investing in research and development of renewable sources. This is also because these countries have realized the business opportunities that renewables present, especially in the near future.

Spain on the other hand has had a good adoption of renewable compared to other countries worldwide.

As analyzed in previous sections, several laws such as ***Real Decreto 1/2012*** or ***Real Decreto 413/2014*** directly affected the trend of most renewable energies, limiting their growth and establishing a stagnation in the growth of their use. Socio-economic effect of the crisis and the deficit in the electricity sector also contributed to the reduction of premiums and incentives for the installation of renewables. Regarding all this, it is clear that politics and changes in legislation have a huge impact in the trend of renewables. In addition, it can be observed that one of the biggest impulses received by the use renewables were the introduction of the special remuneration systems that were introduced with ***Real Decreto 661/2007***. These remuneration systems caused the amount of renewable power installed in the state to skyrocket.

As determined in the analysis, Spanish percentage of consumed renewables compared to other sources is higher than European average and worldwide average.

The percentage of consumption from renewables in Spain went from 6,97% in 1990 almost doubling to 13,38% in 2017. A very noticeable percentage.

Two of the main renewable sources that have been receiving the major investments and adoption are wind and solar energies. Spain being a country with relatively hot climate and strong winds has the potential and the resources to push these to renewables forward in the coming years.

8.2. Future scenario of renewables

The second objective was to determine the future trends of renewables and how these compare to targets established by the *Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030* at a National level.

These objectives have been achieved. Data of consumed renewable energy from *Red Eléctrica Española (REE)* from January 2007 to December 2019 was analyzed. The results obtained from the analysis and the answers to the second research question are the following;

According to the data analyzed, the trend of renewables in the future is a clear increase, especially for wind and solar sources. The applies to Spain and other countries worldwide. The remaining sources such as Hydraulic will remain the same o even have a decrease in energy production and consumption. It is not very clear the role that waste and other renewable sources will play. From the data analyzed, it can be concluded that solar and wind energy are the sources with the largest increase in trend for the future as this trend is already noticeable.

Comparing the forecasts by the statistical models with the targets established by *Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030* at a National level; it is concluded that generally, the forecast and the targets superpose very well in the case of Hydraulic and wind sources. The forecasts for solar thermal and solar photovoltaic on the other hand do not coincide with the targets established by *PNIEC* for 2020. This is due to the fact that the forecasts made with the models contemplate the actual trend and extrapolates this trend to the future. These statistical models take into account past political policies and socio-economic behavior inherent in the data. *Plan Nacional Integrado de Energía y Clima (PNIEC)* on the other hand contemplates changes in trend

as new wind and solar power facilities are planned to be built. New political policies are planned to be implemented, which may cause a drastic change in trend in the future.

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ANNEX 1

The following is the dataset used and analyzed for the predictions.

	Hydraulic	WInd	Solar photovoltaic	Solar thermal	Other renewables	Waste renewables
ene/07	2265,540	2167,747	10,395	-	158,513	54,797
feb/07	3018,536	2895,320	12,963	-	152,188	47,474
mar/07	3928,392	3123,878	21,991	0,431	166,093	56,789
abr/07	2867,464	1382,621	26,108	0,342	144,600	55,607
may/07	2837,474	2641,214	36,127	0,558	156,540	54,418
jun/07	2309,410	1818,326	40,743	0,883	154,406	54,170
jul/07	2454,750	1946,919	51,927	1,256	154,109	69,335
ago/07	1770,973	2468,818	56,508	1,116	158,968	65,328
sep/07	1376,306	2055,451	60,435	0,639	151,538	66,962
oct/07	1712,530	1927,348	57,698	1,214	173,100	70,322
nov/07	1342,248	2769,183	54,378	0,997	173,978	66,776
dic/07	1221,884	2414,839	54,662	0,191	179,215	74,850
ene/08	1393,467	2664,582	59,581	1,084	171,681	62,856
feb/08	957,900	2035,723	73,405	0,797	169,740	68,153
mar/08	1076,037	4132,368	108,565	1,461	165,433	73,632
abr/08	2740,009	3389,457	131,048	0,958	174,106	70,406
may/08	3370,347	1769,216	137,025	0,942	180,069	44,448
jun/08	3175,810	2125,689	196,413	1,963	168,906	66,034
jul/08	2182,176	2184,157	240,443	2,038	155,853	76,903
ago/08	1539,701	2034,346	298,529	1,980	178,687	65,671
sep/08	1313,425	2148,060	328,088	0,859	164,365	57,506
oct/08	1095,163	2516,475	334,330	0,866	181,406	62,113
nov/08	1592,800	3485,325	335,405	1,270	183,415	64,926
dic/08	2498,649	3674,448	255,163	1,160	184,713	69,997
ene/09	2274,497	3527,977	261,256	0,690	207,809	77,267
feb/09	3482,203	3244,297	396,228	1,236	202,364	52,368
mar/09	2794,399	3125,394	528,736	2,323	203,670	55,431
abr/09	2205,653	3106,598	569,739	7,204	231,070	75,936
may/09	2585,816	2730,598	672,353	7,658	199,641	59,490
jun/09	2128,045	2353,515	643,834	6,753	197,786	69,365
jul/09	1758,419	2482,251	717,298	12,413	198,714	76,327
ago/09	1449,827	2293,089	663,412	23,868	206,090	62,383
sep/09	993,209	2489,991	511,535	17,539	224,215	58,833
oct/09	1258,946	3138,623	502,210	23,446	254,313	70,121
nov/09	2027,007	4817,904	362,000	16,183	193,951	67,174
dic/09	3228,387	4942,602	243,822	10,511	196,822	68,422
ene/10	5178,649	4304,433	263,119	13,152	193,815	72,933

feb/10	4067,306	4637,900	305,074	11,682	174,655	62,903
mar/10	5816,541	4570,156	481,510	23,732	178,251	42,702
abr/10	4720,054	2667,345	590,409	36,920	203,174	66,883
may/10	3862,881	3655,899	711,443	69,084	224,105	57,307
jun/10	3555,038	2615,311	685,333	72,533	223,560	70,201
jul/10	2896,777	2845,760	785,816	104,591	212,803	75,138
ago/10	2036,831	2937,764	723,066	121,899	212,171	70,552
sep/10	1530,458	2337,395	631,379	100,917	197,889	68,536
oct/10	1601,507	3967,327	548,485	71,745	210,121	71,726
nov/10	2611,521	4366,546	382,180	31,619	202,760	77,486
dic/10	3956,243	4639,515	314,976	33,747	225,744	72,177
ene/11	5119,512	4033,540	351,257	39,743	309,539	64,677
feb/11	2998,051	4053,567	505,139	88,657	288,164	57,921
mar/11	3910,363	4716,543	536,661	98,457	304,184	39,860
abr/11	3537,938	3424,459	661,694	137,835	301,262	60,268
may/11	2797,500	3186,035	748,625	160,441	311,497	47,065
jun/11	2070,305	2975,674	812,116	247,971	277,166	69,572
jul/11	1661,925	3310,882	859,520	284,060	311,495	70,695
ago/11	1520,945	2783,414	808,576	235,329	315,060	64,464
sep/11	1221,592	2354,842	735,895	228,558	330,500	61,983
oct/11	1250,279	3178,557	629,611	172,950	324,598	66,643
nov/11	2163,287	3836,275	365,450	81,174	315,315	63,633
dic/11	2185,620	4623,463	426,208	86,466	325,254	69,276
ene/12	1631,153	3668,234	504,687	117,342	323,447	67,258
feb/12	1224,635	5053,681	660,330	200,342	310,310	53,332
mar/12	1341,011	3845,592	770,143	235,113	320,467	40,775
abr/12	1744,143	5336,981	658,518	177,777	298,755	62,180
may/12	2535,025	3735,031	863,506	348,382	314,139	50,965
jun/12	2106,114	3473,616	875,875	414,749	326,041	64,279
jul/12	1664,189	3039,878	941,619	541,317	327,981	70,588
ago/12	1334,812	3181,746	865,184	485,127	295,045	67,696
sep/12	1035,499	3953,821	692,373	368,643	282,008	63,810
oct/12	1388,894	3147,333	595,431	289,155	314,367	61,960
nov/12	1986,471	4622,287	372,486	133,962	327,118	58,540
dic/12	2661,620	5466,330	402,108	135,585	351,405	58,405
ene/13	3014,449	6316,803	446,284	113,494	358,310	59,527
feb/13	3551,162	5370,057	527,718	204,009	330,340	53,118
mar/13	4586,971	5763,164	566,720	125,370	355,452	46,529
abr/13	5389,986	4424,982	763,804	300,894	364,849	25,231
may/13	3819,093	3970,877	872,919	499,268	371,371	29,502
jun/13	3208,936	3875,785	930,953	647,330	347,356	27,608
jul/13	2723,827	2885,903	974,759	758,523	386,750	31,755

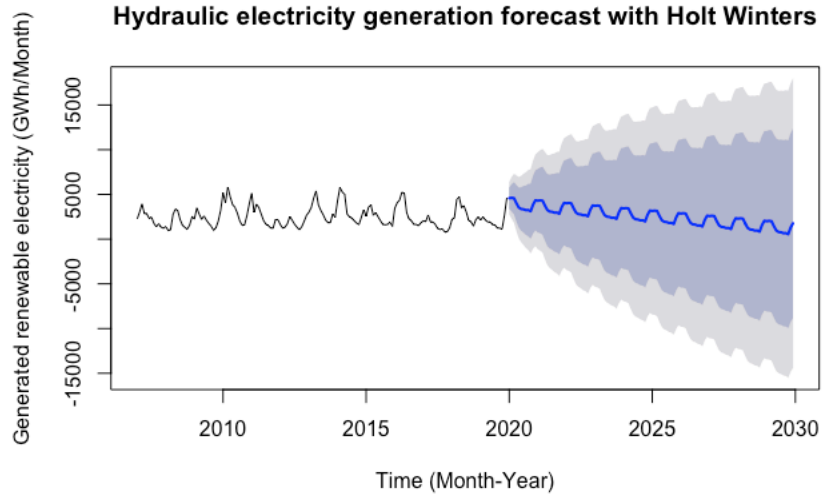
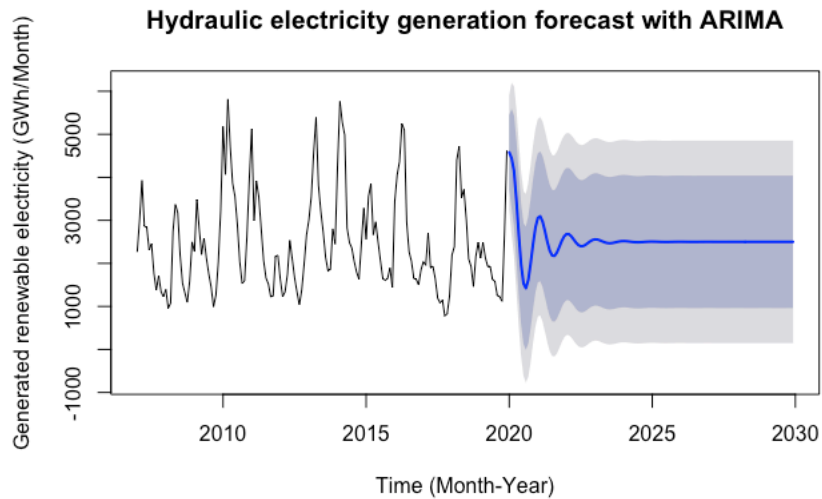
ago/13	2143,818	3453,693	896,902	661,856	370,019	47,027
sep/13	1826,149	3239,162	759,635	478,955	349,040	62,915
oct/13	1866,732	3988,546	634,767	294,242	356,573	55,457
nov/13	2804,998	6458,348	513,575	199,224	358,832	56,372
dic/13	2449,315	4966,072	439,239	158,362	385,394	60,698
ene/14	4261,393	6570,962	377,519	79,801	380,896	49,340
feb/14	5763,251	5917,526	434,383	103,265	293,997	35,868
mar/14	-	-	735,971	385,175	305,878	32,435
abr/14	4986,857	3978,165	791,986	435,527	266,468	51,170
may/14	2826,765	4177,876	924,515	729,936	330,192	60,551
jun/14	2485,722	3310,964	903,766	687,288	330,073	58,361
jul/14	2354,817	3637,133	951,578	811,153	338,214	67,005
ago/14	2044,885	2916,901	914,035	833,178	349,913	55,682
sep/14	1797,145	2145,217	686,973	389,596	333,100	68,961
oct/14	1632,018	3398,888	647,940	289,337	300,499	64,805
nov/14	2452,065	5093,132	385,421	90,187	288,090	60,302
dic/14	3284,049	4788,821	453,840	124,472	298,996	73,591
ene/15	2554,830	4954,531	518,440	176,951	301,804	64,153
feb/15	3559,006	5992,547	494,228	190,925	245,330	59,516
mar/15	3845,584	4907,496	713,262	415,829	274,298	72,008
abr/15	2662,812	3933,920	755,910	393,160	201,678	47,499
may/15	2967,173	4841,183	924,092	694,839	274,889	64,893
jun/15	2497,589	2903,929	889,206	734,054	288,141	73,037
jul/15	2060,398	3113,294	933,158	888,918	309,892	73,161
ago/15	1643,720	3287,344	831,901	607,623	317,503	70,309
sep/15	1609,521	3020,625	722,204	483,250	307,429	70,194
oct/15	1650,167	3901,151	537,712	188,169	314,765	75,952
nov/15	1892,683	3724,598	529,699	226,818	307,126	74,485
dic/15	1439,097	3537,269	393,750	84,699	289,738	72,842
ene/16	3441,828	5624,578	364,458	59,914	270,625	66,351
feb/16	4052,882	6109,531	480,081	133,010	261,567	53,485
mar/16	4366,547	5443,970	709,289	387,861	255,630	66,529
abr/16	5244,882	4441,296	721,480	408,323	209,994	39,262
may/16	5101,206	3933,103	807,003	498,795	277,221	39,160
jun/16	2956,172	3271,335	924,052	813,991	287,561	69,139
jul/16	2273,200	3521,942	918,530	825,325	311,080	75,308
ago/16	2047,078	3652,945	895,839	805,819	326,727	73,403
sep/16	1653,646	2713,827	766,070	595,627	307,663	75,080
oct/16	1631,830	2389,618	584,445	284,703	306,358	74,217
nov/16	1499,053	3906,853	426,513	139,700	304,817	74,121
dic/16	1846,562	2687,663	379,705	118,136	306,423	79,339
ene/17	2040,641	4812,549	476,155	149,212	327,461	72,734

feb/17	1956,588	4928,506	445,437	88,741	289,720	63,647
mar/17	2701,231	4724,369	717,349	340,845	269,561	70,867
abr/17	1897,982	4196,147	836,605	535,255	232,817	61,682
may/17	1935,428	3465,996	872,980	607,898	298,767	45,922
jun/17	1637,871	3192,372	881,516	761,902	302,617	81,468
jul/17	1193,059	3387,355	917,560	812,880	333,389	83,371
ago/17	1082,727	3343,930	819,232	692,435	316,027	80,368
sep/17	1147,848	2872,132	775,734	608,143	309,496	77,905
oct/17	773,650	3208,246	682,150	398,793	309,764	80,610
nov/17	832,696	3981,906	540,732	220,652	307,753	77,924
dic/17	1250,895	5793,446	432,305	131,195	312,976	80,509
ene/18	2194,882	5348,580	444,543	112,388	296,332	77,266
feb/18	2388,895	4680,466	511,076	229,808	301,601	67,136
mar/18	4402,434	7726,428	591,497	233,956	271,634	77,633
abr/18	4718,449	4461,454	702,009	325,935	237,806	77,872
may/18	3523,168	3319,732	813,591	477,210	291,746	35,346
jun/18	3718,077	2632,680	819,813	551,293	304,801	65,936
jul/18	3027,392	2576,189	935,321	858,898	324,173	79,705
ago/18	2105,597	3132,685	847,495	688,558	317,407	81,187
sep/18	1926,845	2458,499	722,201	465,637	320,236	78,624
oct/18	1462,712	4321,987	571,934	292,493	297,769	81,018
nov/18	2162,065	4559,010	376,485	78,576	293,487	68,737
dic/18	2486,725	4363,779	430,215	109,575	300,447	83,614
ene/19	2127,215	6027,204	507,327	166,150	304,554	73,614
feb/19	2483,405	3695,710	634,799	261,979	285,704	69,241
mar/19	2132,449	4921,198	812,266	477,846	310,426	78,983
abr/19	1925,254	4663,671	702,886	379,269	275,235	78,096
may/19	1935,033	4677,094	939,910	740,998	283,125	50,064
jun/19	1626,371	3286,928	932,032	775,058	286,543	76,417
jul/19	1581,869	3440,318	1000,503	722,867	326,711	80,477
ago/19	1254,740	2890,785	1012,420	745,499	321,410	79,105
sep/19	1225,078	3894,194	859,861	454,732	301,968	77,785
oct/19	1119,496	3809,008	787,711	303,085	310,565	77,243
nov/19	2657,738	7442,479	522,344	69,971	309,228	74,488
dic/19	4626,521	5463,590	510,502	68,978	300,769	74,302

ANNEX 2

The following are all the plots of the predictions for all renewable sources using Arima and Holt Winters models.

Hydraulic



```

> autoarima
Series: data
ARIMA(2,0,3) with non-zero mean

Coefficients:
          ar1          ar2          ma1          ma2          ma3          mean
      1.5582   -0.8193   -0.6938   0.1410   0.2021  2500.4955
s.e.  0.0886    0.0817    0.1276   0.1045   0.1129   131.8385

sigma^2 estimated as 455541:  log likelihood=-1235.38
AIC=2484.76  AICc=2485.52  BIC=2506.11
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

Call:
HoltWinters(x = data)

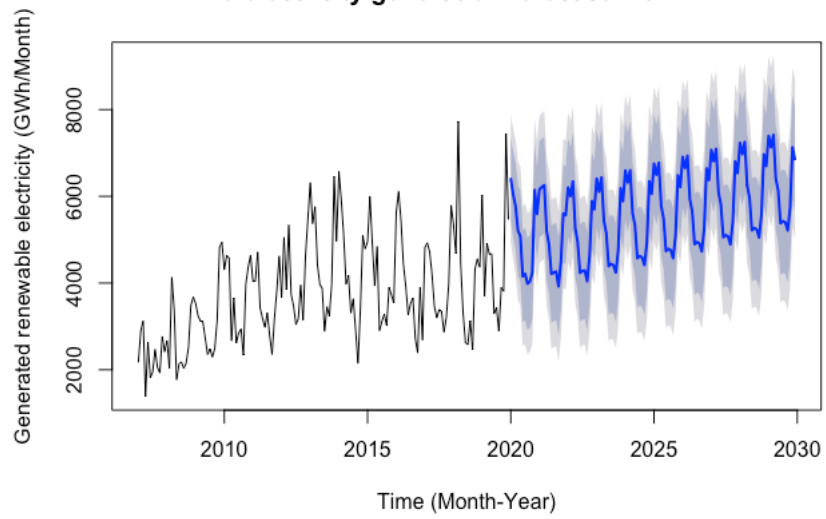
Smoothing parameters:
alpha: 0.7988529
beta : 0
gamma: 1

Coefficients:
      [,1]
a  3865.22065
b   -23.83433
s1   735.64541
s2   798.68696
s3   784.86294
s4   253.50397
s5  -204.59832
s6  -356.86193
s7  -358.77254
s8  -438.86319
s9  -397.06745
s10 -507.49632
s11  252.89918
s12  761.30035

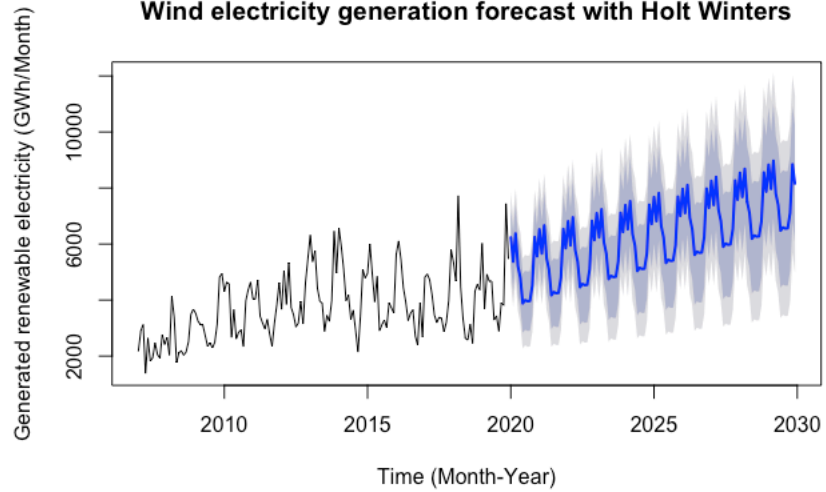
```

Wind

Wind electricity generation forecast with ARIMA



Wind electricity generation forecast with Holt Winters



```

> autoarima
Series: data
ARIMA(3,0,0)(2,1,1)[12] with drift

Coefficients:
          ar1      ar2      ar3      sar1      sar2      sma1      drift
      0.2023  0.2004  0.1941  0.1527 -0.1616 -0.8542  13.4168
s.e.  0.0888  0.0860  0.0881  0.1653  0.1398  0.2082  3.5083

sigma^2 estimated as 551798:  log likelihood=-1160.8
AIC=2337.59  AICc=2338.66  BIC=2361.35
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

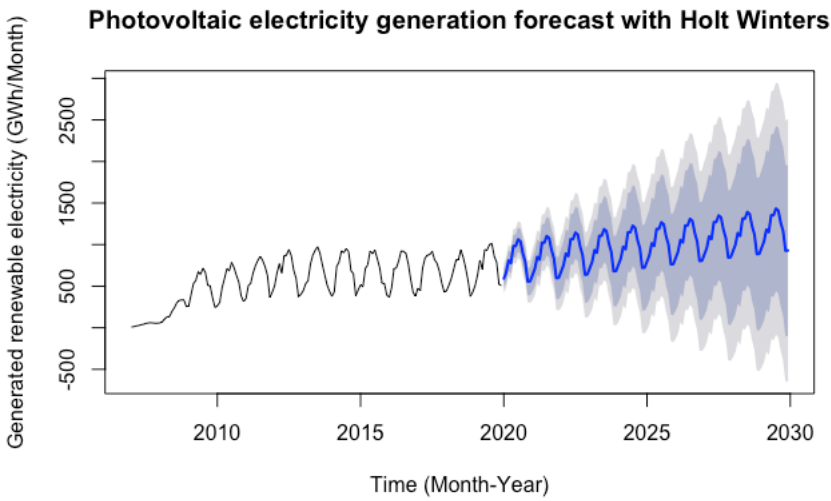
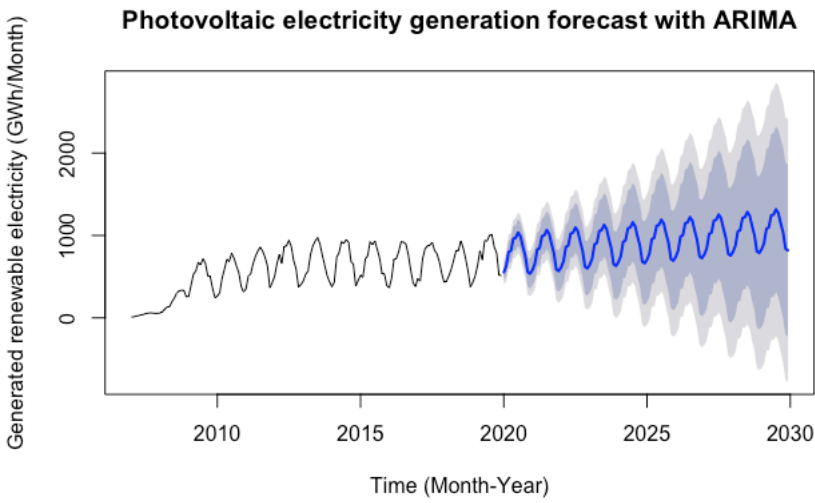
Call:
HoltWinters(x = data)

Smoothing parameters:
alpha: 0.1065994
beta : 0
gamma: 0.3818498

Coefficients:
          [,1]
a    5043.26762
b      24.03296
s1   1168.03446
s2    282.08257
s3   1260.24263
s4     64.87012
s5   -364.30415
s6  -1306.76150
s7  -1213.79384
s8  -1278.00753
s9  -1290.51762
s10  -775.13631
s11   941.63857
s12   231.53821

```

Solar Photovoltaic




```

> autoarima
Series: data
ARIMA(1,1,1)(0,1,1)[12]

Coefficients:
          ar1          ma1          sma1
      0.6720  -0.8825  -0.6624
s.e.  0.1095   0.0646   0.0982

sigma^2 estimated as 5275:  log likelihood=-817.98
AIC=1643.96  AICc=1644.25  BIC=1655.81
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

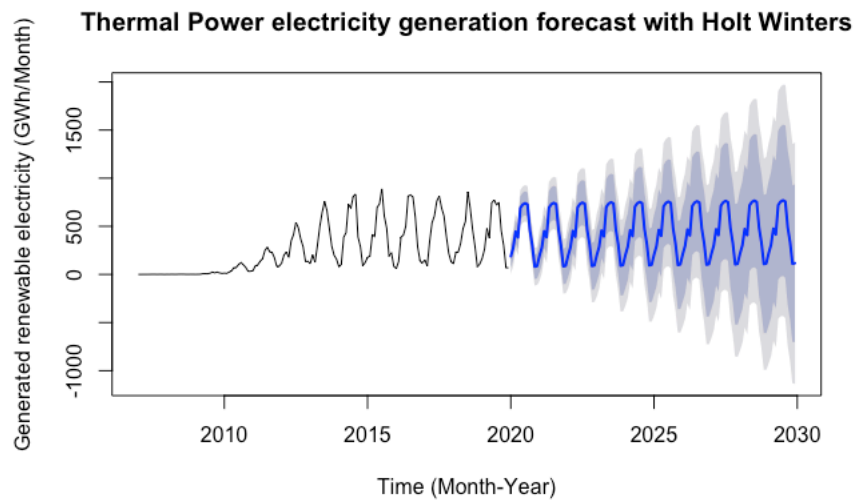
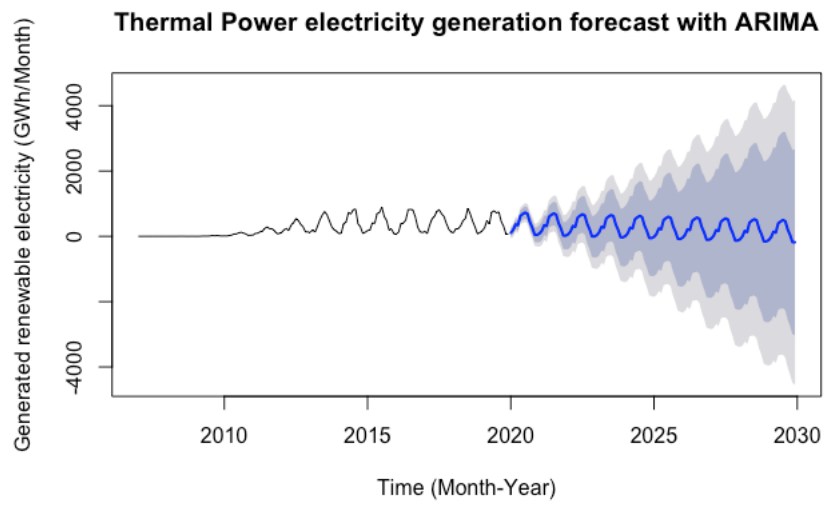
Call:
HoltWinters(x = data)

Smoothing parameters:
alpha: 0.2865793
beta : 0.02585266
gamma: 0.8027697

Coefficients:
      [,1]
a  858.509226
b    3.434819
s1 -270.571045
s2 -197.340383
s3 -58.827656
s4 -93.574099
s5 106.750322
s6 103.801555
s7 179.868323
s8 151.029849
s9   2.653244
s10 -101.238793
s11 -340.186077
s12 -340.764332

```

Thermal Power



```

> autoarima
Series: data
ARIMA(0,1,1)(0,1,1)[12]

Coefficients:
          ma1      sma1
      -0.4838  -0.3565
s.e.   0.1195   0.0958

sigma^2 estimated as 8106:  log likelihood=-846.37
AIC=1698.74  AICc=1698.92  BIC=1707.63
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

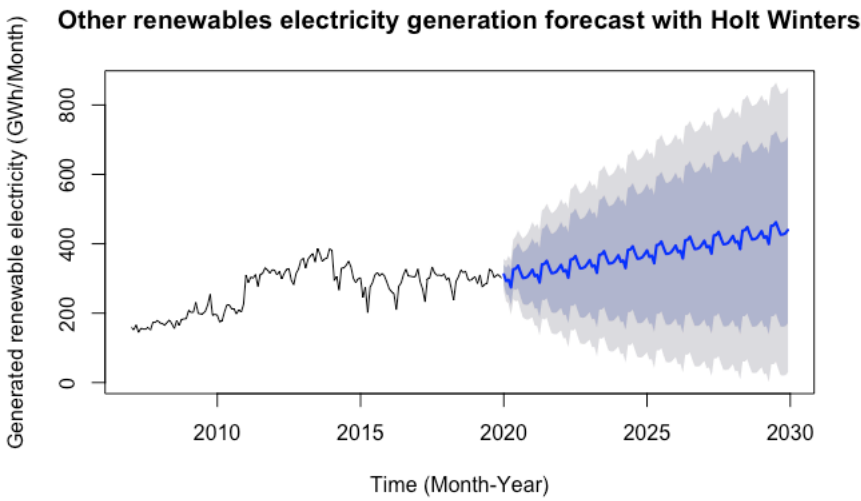
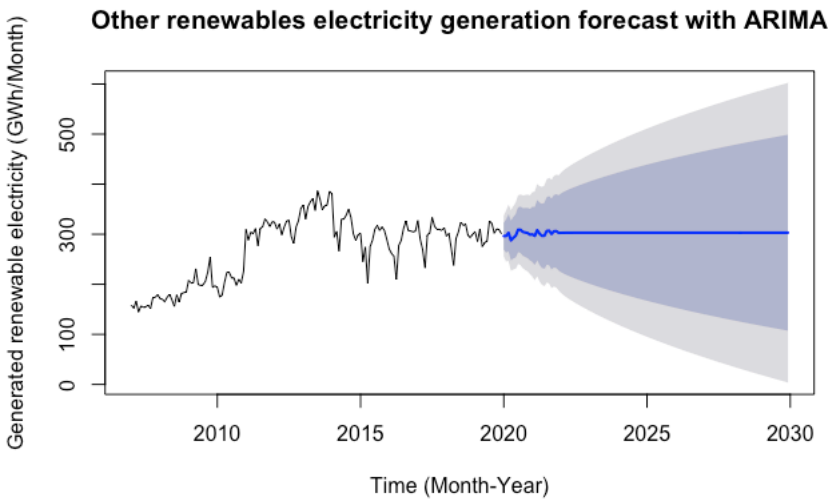
Call:
HoltWinters(x = data)

Smoothing parameters:
alpha: 0.08030636
beta : 0.08422354
gamma: 0.8153377

Coefficients:
          [,1]
a    421.6248939
b      0.2791966
s1  -233.5663057
s2  -146.6545556
s3   23.5504153
s4  -38.1366222
s5  267.0514828
s6  302.7755641
s7  316.4148667
s8  303.0061307
s9   33.8106385
s10 -121.2568781
s11 -343.8593634
s12 -337.8827918

```

Other renewables



```

> autoarima
Series: data
ARIMA(1,1,1)(0,0,2)[12]

Coefficients:
      ar1      ma1      sma1      sma2
      0.5563 -0.8111  0.3155  0.3070
s.e.  0.1518  0.1062  0.0815  0.0692

sigma^2 estimated as 427.6:  log likelihood=-689.07
AIC=1388.14  AICc=1388.54  BIC=1403.36
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

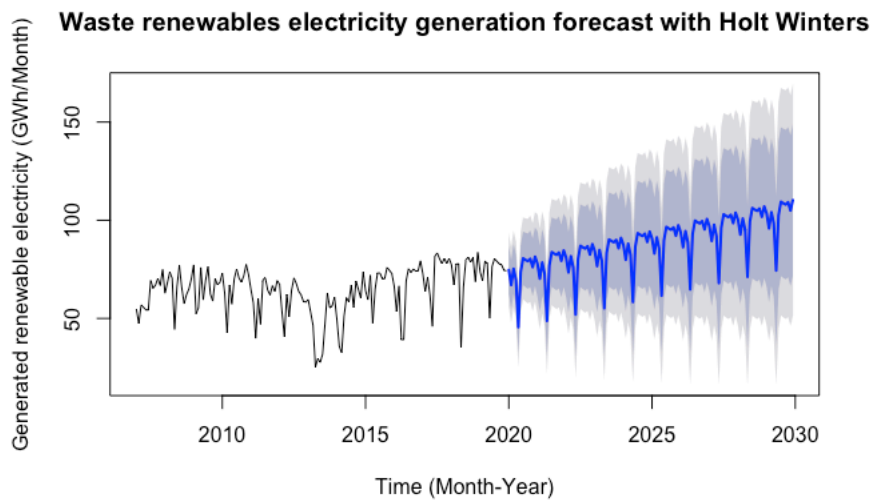
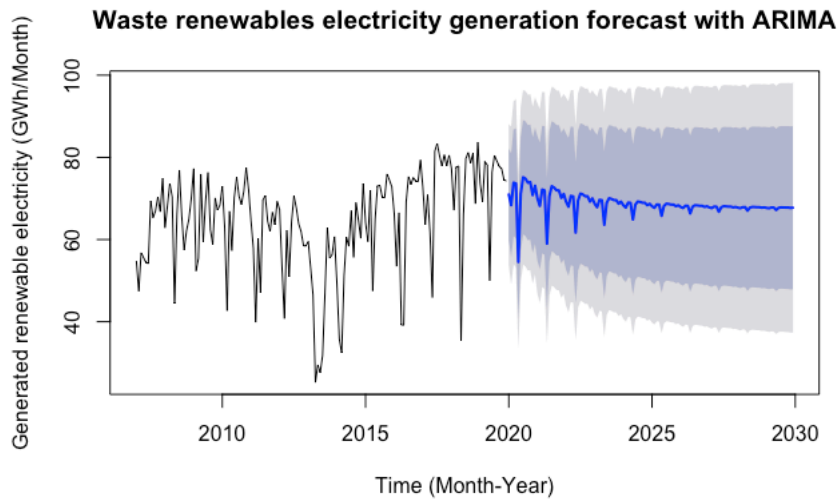
Call:
HoltWinters(x = data)

Smoothing parameters:
alpha: 0.8257729
beta : 0
gamma: 1

Coefficients:
      [,1]
a  301.902556
b   1.158207
s1   8.467352
s2 -11.643762
s3  -8.961439
s4 -32.221642
s5  19.011780
s6  19.139372
s7  27.145266
s8   6.651994
s9 -10.997209
s10 -11.381273
s11  -9.306683
s12  -1.133556

```

Waste



```

> autoarima
Series: data
ARIMA(3,1,2)(2,0,0)[12]

Coefficients:
          ar1      ar2      ar3      ma1      ma2      sar1      sar2
      0.3552  0.1098  0.1450 -0.8560 -0.1326  0.4458  0.1583
s.e.  0.7718  0.3895  0.1036  0.7863  0.7688  0.0799  0.0903

sigma^2 estimated as 75.92:  log likelihood=-554.61
AIC=1125.21  AICc=1126.2  BIC=1149.56
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

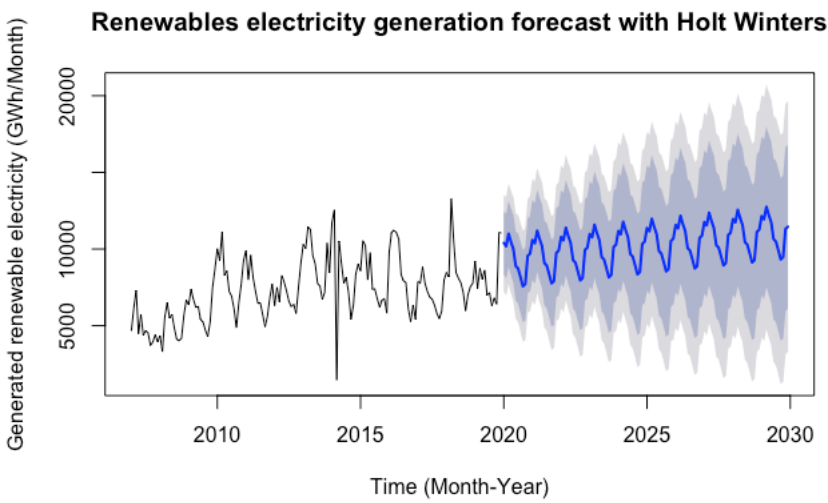
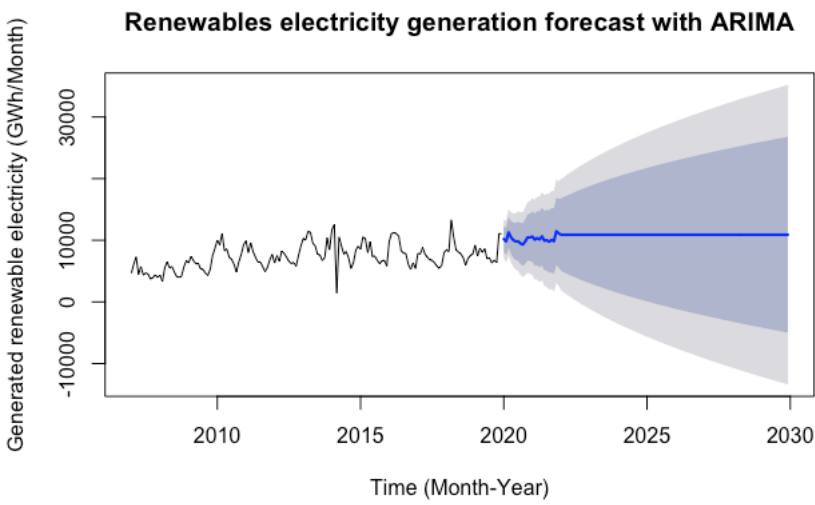
Call:
HoltWinters(x = data)

Smoothing parameters:
alpha: 0.211508
beta : 0.001270965
gamma: 0.4979522

Coefficients:
      [,1]
a    76.1804831
b     0.2668723
s1   -1.7727712
s2   -9.6967142
s3   -1.7082760
s4   -7.6751813
s5  -31.9660363
s6   -4.0090686
s7    2.5571377
s8    1.4767005
s9    0.5727565
s10   1.5191753
s11  -3.0282188
s12   2.0545595

```

Total Renewables




```

> autoarima
Series: data
ARIMA(0,1,1)(0,0,2)[12]

Coefficients:
          ma1      sma1      sma2
      -0.4992  0.1463  0.3735
s.e.    0.0910  0.0743  0.0918

sigma^2 estimated as 2408590:  log likelihood=-1359.26
AIC=2726.53   AICc=2726.79   BIC=2738.7
> hw
Holt-Winters exponential smoothing with trend and additive seasonal component.

Call:
HoltWinters(x = data)

Smoothing parameters:
alpha: 0.1968966
beta : 0
gamma: 0.2645043

Coefficients:
      [,1]
a   9064.5031
b    16.2499
s1  1317.9462
s2  1082.0453
s3  1887.7397
s4  1331.6311
s5   859.0389
s6  -267.4814
s7  -452.9057
s8 -1029.8166
s9 -1645.1786
s10 -1507.8481
s11  309.1708
s12  440.8954

```

ANNEX 3

The following is the R script code used for making the predictions

```
# Load packages and house keeping

library('ggplot2')

library('forecast')

library('tseries')

library(readr)

library(tsibble) #tsibble for time series based on tidy principles

library(fable) #for forecasting based on tidy principles

library(ggfortify) #for plotting timeseries

library(forecast) #for forecast function


#TREATING DATA FROM REE

# Loading of files

Renewables_REE <- read_delim("Dropbox/Kronos/Data/Renewables_REE.csv"

                             ,";", escape_double = FALSE, trim_ws = TRUE)

renewables = Renewables_REE[1:6]


# Transform data into time series

data_all = ts(Renewables_REE, start = c(2007,1), frequency = 12)

data_ren = ts(renewables, start = c(2007,1), frequency = 12)


# TREATING DATA FROM PNIEC

# Load data from PNEIC

pniec <- read_delim("Dropbox/Kronos/Data/pniecregen.csv",

                    ,";", escape_double = FALSE, trim_ws = TRUE)


#Transfrom PNIEC data into time series

datap = ts(pniec$Wind, start = c(2015),end=c(2030), frequency = 0.2)
```

```

# EXPLORING DATA (THE BIG PICTURE)

# Plot data

theme_set(theme_bw())

autoplot(data_all) +

  ggtitle("Time Series of consumed renewables") + ylab("Consumed renewable electricity
(GWh/Month)") + xlab("Time (Month-Year)") +

  theme(plot.title = element_text(hjust = 0.5)) #for centering the text


# Times series plot of renewable sources

theme_set(theme_bw())

autoplot(data_ren) +

  ggtitle("Time Series of consumed renewables") + ylab("Consumed renewable electricity
(GWh/Month)") + xlab("Time (Month-Year)") +

  theme(plot.title = element_text(hjust = 0.5)) #for centering the text


# EXPLORING DATA (Each Renewable Source)

# Load data

re <- Renewables_REE$Total

data = ts(re, start = c(2007,1), frequency = 12)


# Time series component plot

autoplot(components) +

  ggtitle("Decomposition of consumed renewable electricity") +

  xlab("Time (Month-Year)") + ylab("Consumed renewable electricity (GWh/Month)") +

  theme_bw() +

  theme(plot.title = element_text(hjust = 0.5),

    legend.position = "bottom")


# Time series seasonal plot

ggseasonplot(data)+

theme(plot.title = element_text(hjust = 0.5)) + # to center the plot title

  ylab("Consumed newable electricity (GWh/Month)") +

```

```

ggtitle("Seasonal plot of consumed renewable electricity")

# VALIDATION TEST

# Load data
re <- Renewables_REE$Hydraulic

# Set data as time series
data = ts(re, start = c(2007,1), frequency = 12)
data_all = ts(Renewables_REE, start = c(2007,1), frequency = 12)

#Model testing Arima
training = window(data, end=c(2016,12))
test = window(data, start=c(2017,1))
training %>% ets %>% forecast(h=length(test)) -> fc
plot(fc,type="l", lty=2, main= "Hydraulic electricity generation forecast with ARIMA",
      xlab="Time (Month-Year)", ylab = "Generated newable electricity (GWh/Month)")
lines(test, type="l", lty=2)

#Model testing Holt Winters
training = window(data, end=c(2016,12))
trainingh = HoltWinters(training)
test = window(data, start=c(2017,1))
forecast(trainingh, h=length(test)) -> fc
plot(fc,type="l", lty=2, main= "Hydraulic electricity generation forecast with HoltWinters",
      xlab="Time (Month-Year)", ylab = "Generated newable electricity (GWh/Month)")
lines(test, type="l", lty=2)

# FORECASTING

# Load data
re <- Renewables_REE$SThermal
pn <- pniec$SThermelec

```

```

# Set data as time series

data = ts(re, start = c(2007,1), frequency = 12)

data_all = ts(Renewables_REE, start = c(2007,1), frequency = 12)

datap = ts(pn, start = c(2015),end=c(2030), frequency = 0.2)


# ARIMA forecasting + Plot

autoarima=auto.arima(data)

# simple plot to see seasonality

plot(forecast(autoarima, h=24), main= "Solar thermal electricity generation forecast with ARIMA",
      xlab="Time (Month-Year)", ylab = "Generated renewable electricity (GWh/Month)")


# Holt Winters forecasting + Plot

hw = HoltWinters(data)

forecasthw = forecast(hw, h=120)

plot((forecasthw), main= "Solar thermal electricity generation forecast with HoltWinters",
      xlab="Time (Month-Year)", ylab = "Generated renewable electricity (GWh/Month)")

lines(datap, type="l", lty=2) #line for PNIEC pronsstication)

legend("topleft", legend=c("Forecast", "Target PNIEC"),
      col=c("blue", "black"), lty=1:2, cex=0.8)


# ARIMA and Holt Winters forcating parameters

autoarima

hw


# Cleaning environment + packages + plots + console + mind

# Clear environment

rm(list = ls())

# Clear packages

detach("package:datasets", unload = TRUE) # For base

```

```
# Clear plots  
dev.off() # But only if there IS a plot  
# Clear console  
cat("\014") # ctrl+L  
# Clear mind :)
```